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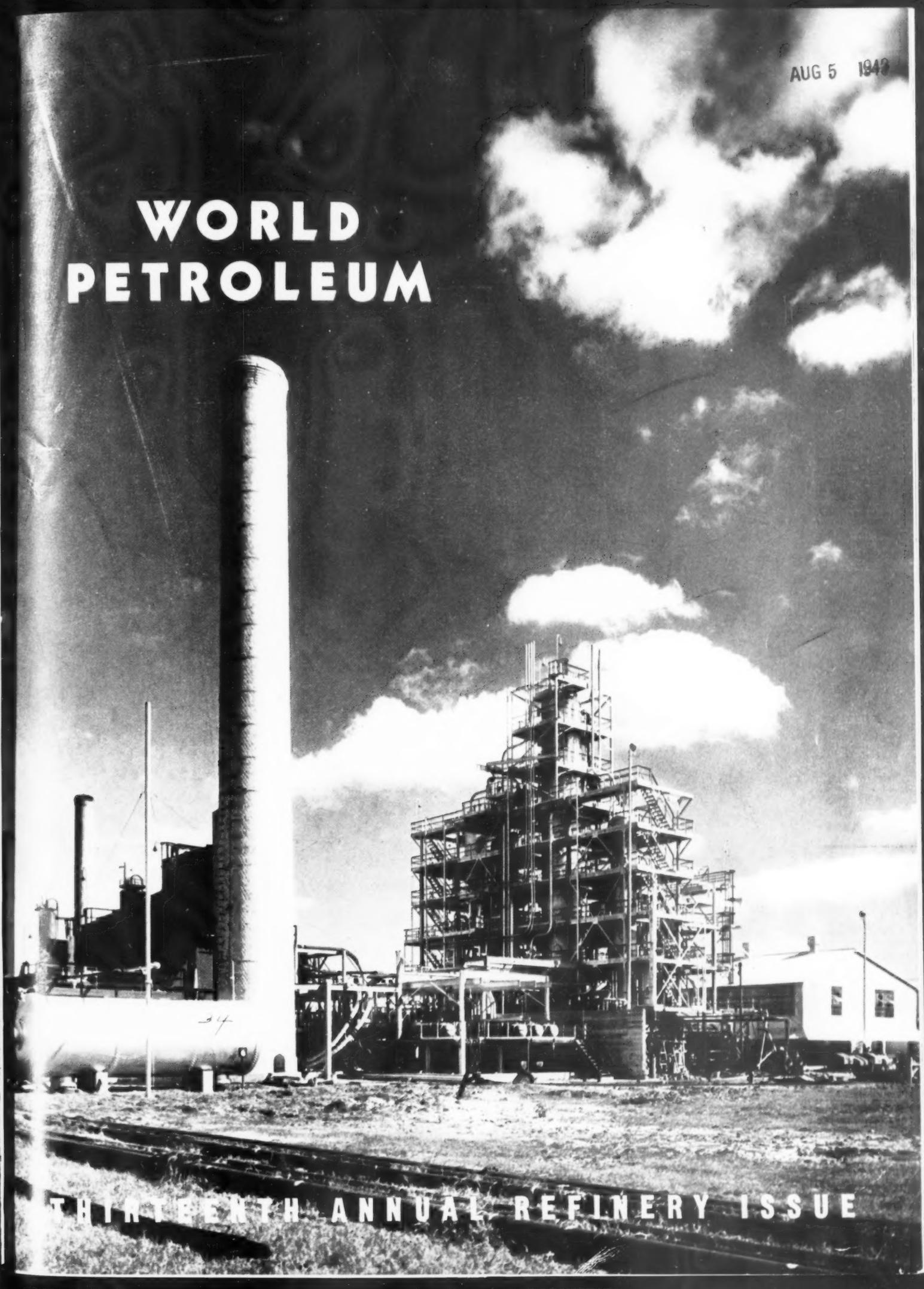

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INCORPORATING PETROLEUM EQUIPMENT EXPORTER

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EDITORIAL

OIL'S WAR RECORD—AND ITS BACKGROUND

WHEN the full history of the present war comes to be written one of its inspiring chapters will be the record of the tremendous task accomplished by the oil industry of the United States. Transformation of its complex and highly efficient peacetime organization into a machine geared primarily to war production, revolutionizing its transportation methods and radically altering its established manufacturing processes to make the ratios of its various products fit the demands of military requirements—all these or any one of them presented difficulties that would have seemed well nigh insuperable under ordinary conditions.

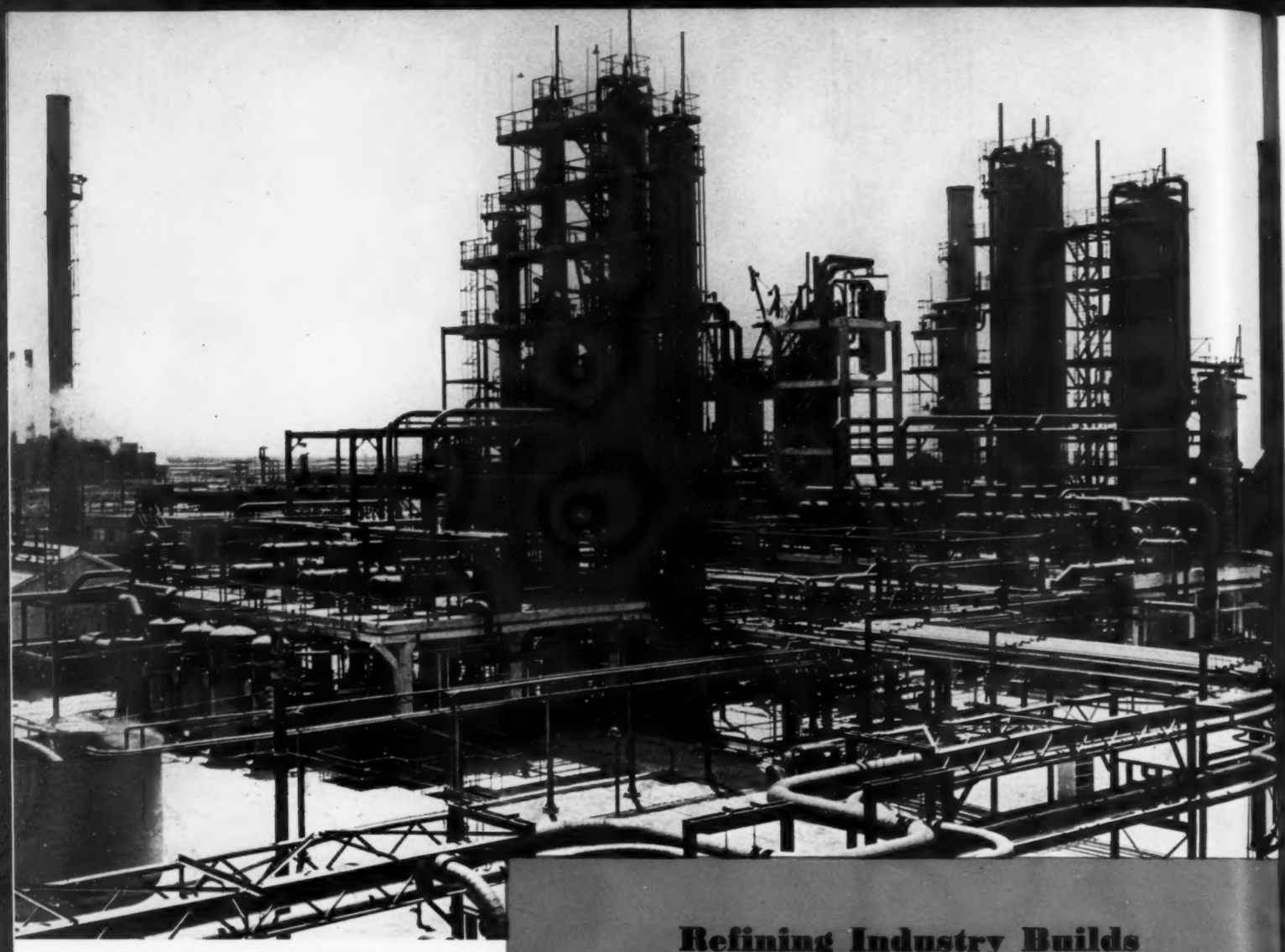
On top of these fundamental changes however the industry has been called upon to provide facilities for the production of a wide range of new and specialized products for purely military use in quantities that would have seemed fantastic only two years ago. It has faced the necessity not only of satisfying the mounting demands of a swiftly expanding army, navy and air force but also of supplying the major needs of allied nations, making this country in the words of Admiral Young "the filling station of the world's democracies". It has had to accomplish this in the face of inadequate supplies of structural materials hitherto regarded as indispensable, forcing the discovery of substitutes, the improvisation of new procedures and the adaptation of outmoded equipment to current use.

Viewed solely as a feat of construction the erection of hundreds of new plants and units, employing processes which in many cases had to be transferred from laboratories and research stations to commercial production without passing through the intermediate stages of experimental and pilot plant tests to which they customarily would be subjected must be regarded as an epic industrial achievement. Never before has a building feat of such proportions, involving so much careful design and such thorough provision for the exact performance of intricate operations, been carried out in so short a time. It has taxed the ingenuity of the industry's engineering corps, strained the human and material resources of construction firms and involved an incredible expenditure of energy and labor on the part of all those who have participated in the undertaking. Its success is written in the flights of planes that fill the skies over enemy strongholds and battle fronts, in the unending movement of the greatest shipping fleets that ever plowed the seas and in the transport and fueling of the most powerful aggregation of motorized military equipment ever brought into existence.

All this expenditure of toil and money would not have been sufficient however except for the astonishing technical advances that have taken place since the program of war preparation was launched. Out of the research laboratories on which the oil industry has expended hundreds of millions of dollars for many years have come new and bewildering combinations of hydrocarbon molecules resulting in improved methods of hydrogenation, polymerization, isomerization and other polysylabic processes, new forms of catalysts, new types of additives—all leading to fuels of higher octane, to higher yields and to the utilization of low grade and waste materials for transformation into high grade products. The contribution of the men behind the retorts and microscopes of the oil industry's laboratories to the saving of lives among our own combatants and the overwhelming of the enemy is one of immeasurable value.

Nor should it be overlooked that these centers of research, the knowledge and skill and experience of those who man them, never would have come into existence except for the highly competitive character of the oil industry, the never ceasing effort to improve the quality of its products and its readiness to spend time and money in the development of processes and products with seemingly only a remote relationship to marketing application. No government controlled monopoly, no bureaucratic management ever has matched nor ever could achieve such progress as has resulted from the exercise of free initiative under the stress of aggressive competition and the struggle for survival in a constantly changing industrial world. There is a lesson for members of the oil industry—and for all other lines of endeavor for that matter—in the evidence of technical preparedness and adaptability to changed conditions revealed by all ranks of the oil army. It is the lesson that freedom of enterprise is their most precious possession, to be defended at all hazards against the open assaults and covert attacks that are certain to be made upon it.

Left: Refinery Fractionating Tower. Photo courtesy Frick Reid Supply Corp.



Now operating at maximum capacity is this new Gulf Oil Corporation 100-octane gasoline plant recently completed at Port Arthur, Texas. The entire output of this unit is being supplied to the armed forces.

Refining Industry Builds

A BILLION DOLLAR WAR MACHINE

In Greatest Construction Job Ever Attempted It Supplies United Nations With Sinews Needed in the Fight for Freedom.

THE most gigantic construction task ever attempted by the petroleum industry is rapidly advancing toward completion. Its demands in effort, materials and money have been too great for comprehension stated merely in statistics. To be appreciated the work must be viewed in the concrete form of vast plants turning out specialized products in quantities hitherto undreamed of, in complex processes yielding new and essential materials and in the adaptation of established mechanism and procedure to novel and important uses.

Transformation of the American refining industry to a virtually complete war footing is only one of many industrial miracles accomplished by the effective teamwork of men within its ranks backed by the authority and resources of their government, but it is one of the most impressive when measured by the speed and efficiency with which it has been carried out and by its all-important contribution to the drive toward victory. It has been one of the most difficult too because military requirements for petroleum products have risen out of all proportion to the needs originally envisaged and demands are on a constantly ascending scale. Many of these demands have come with little or no advance notice. As the war has spread to ever broadening areas until now it envelops every quarter of the globe and as the progress of the conflict has revealed more and more clearly that its outcome depends upon machines which are useless without liquid fuels and lubricants, the call for oil products in greater and still greater quantities has become ever more insistent. Oil men have been compelled constantly to raise their sights, to put greater pressure upon their hard-working organizations, to find the means and materials for expanding capacity and to develop methods for tapping new sources of supply and putting more power into the products they turned out.

The record of achievement is not complete nor will it be until the last vestiges of opposition to the forces of freedom have disappeared. One of the marvels in what has been done is the constant progress in improving the performance records of war-needed products and in the utilization for high grade products of what formerly were regarded as low grade materials. This has been the immeasurable contribution to the war effort of the research branch of the industry quickly turned to account by its clear visioned engineers and practical operating men. That

technical progress should have made greater strides under the stress of terrific pressure for expanded plant capacity and output than it did in comparable peacetime periods is a tribute to the ability and ingenuity of the industry's great corps of investigators and experimenters and to the experience and the facilities which they brought to their work from the pre-war period.

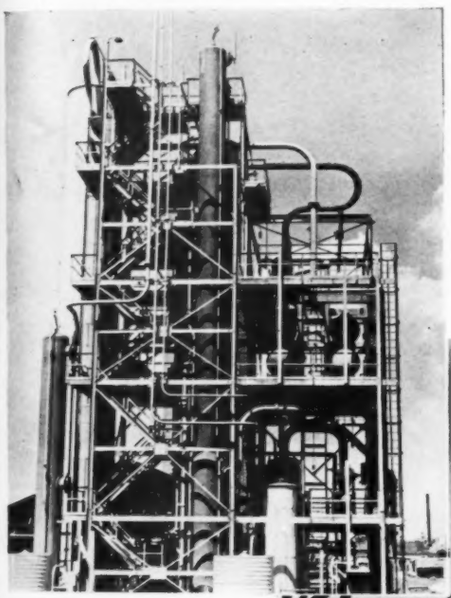
Much of this story cannot yet be told but it is possible to present in part at least the great achievement of the oil industry in providing the forces of the United Nations with the means of attaining the clear superiority on land and sea and in the air which they are now demonstrating and in helping them to round the vital turning point toward ultimate assured success. That is sufficient for the time.

In the readjustment of the refining industry to its present position in which it is essentially a part of the nation's war machine it has passed through three distinct stages. First of these was the national defense movement when the need for increasing the land and naval forces to meet possible attack from without began to be seriously considered and when the provision of an increased volume of petroleum supplies for the military establishment figured in the limited plans then adopted. Second was the period when the country moved closer to the war and assumed the responsibility of serving as the arsenal of democracy and supplying food and fighting equipment to the nations battling against Totalitarianism. That called for increased output of aviation gasoline, fuel oil and lubricants since these were among the weapons most urgently needed. The third and decisive stage opened with the cowardly assault of the Japanese and the entry of the United States into the war as a full-fledged combatant while at the same time continuing to meet the rapidly growing petroleum needs of its allies. This has been the period of multiplying demands and great expansion when the oil industry has been called upon to face conditions and satisfy requirements well outside the scope of its ordinary operations. That it has been able thus far to meet these vastly enlarged demands is a rare tribute to its resourcefulness and ingenuity.

The basis for all this progress, the foundation upon which it has been built, was laid, of course long ago. It originated in the intensely competitive nature of the oil industry and its relentless search for methods adding to the variety of its products and improving their quality. This led to the establishment of great laboratories, magnificently equipped, and to the expenditure of hundreds of millions of dollars in research. Technical progress kept well in advance of utility demand and led even to the origination or acquisition of processes having no immediate commercial application which have proven extremely valuable in meeting conditions created by the war. Except for the state of preparedness to which the industry had brought itself it would have been quite impossible to meet the emergency confronting it during the past two years.

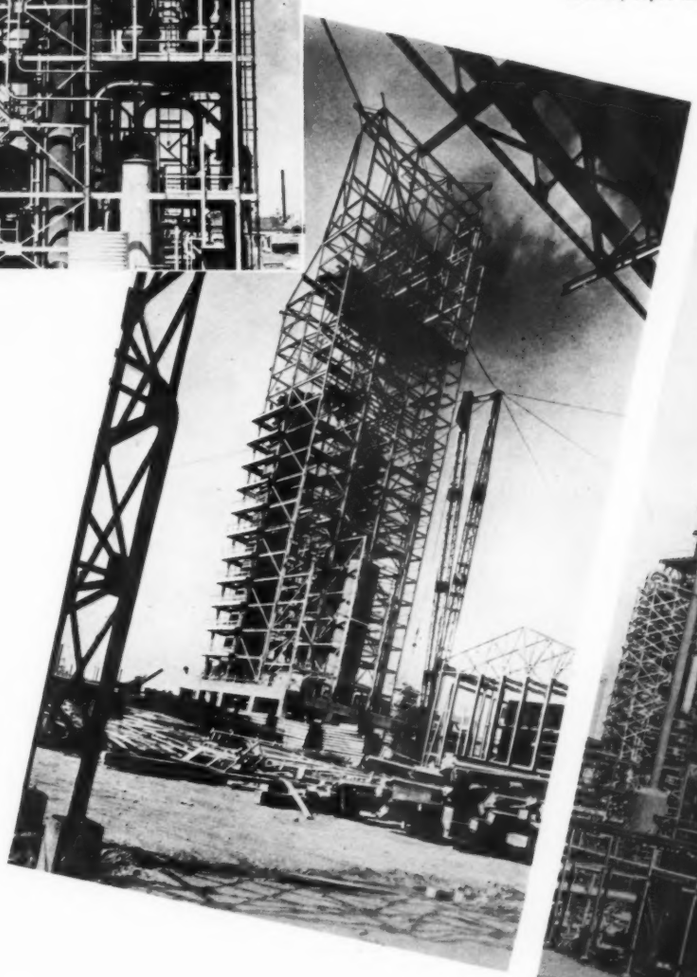
When the forces of aggression began to overrun

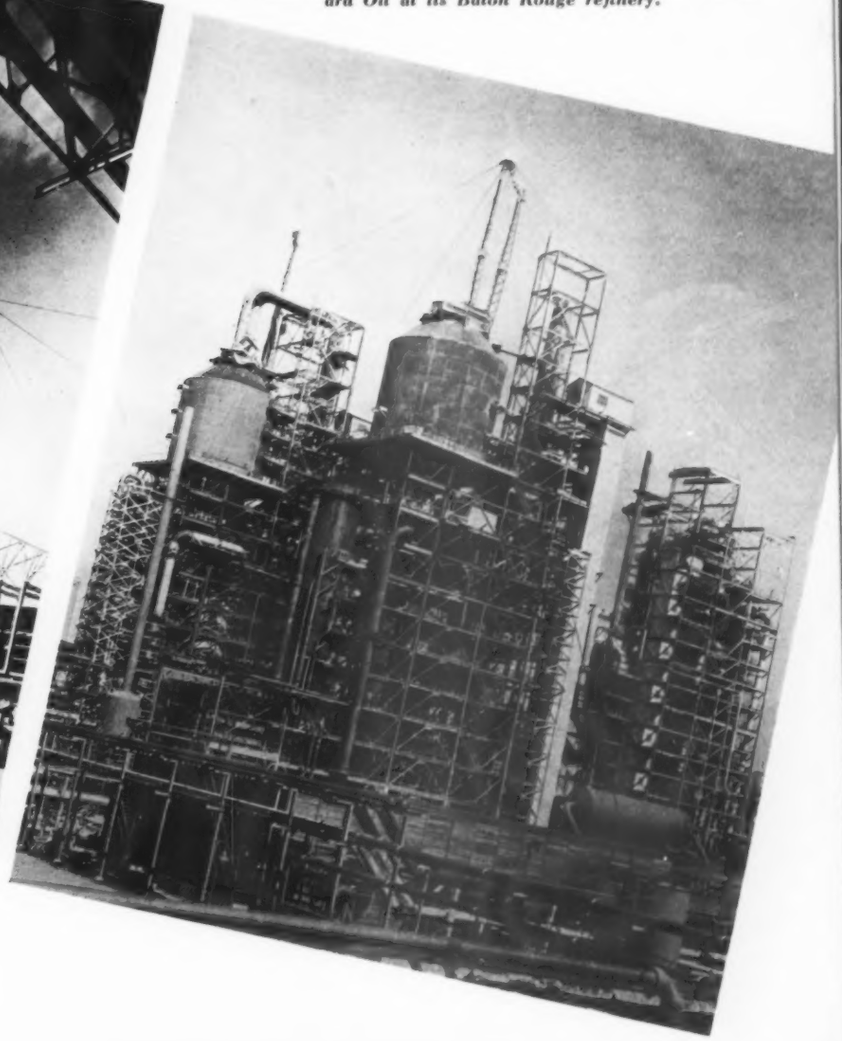
Socony-Vacuum polyform plant in Indiana.

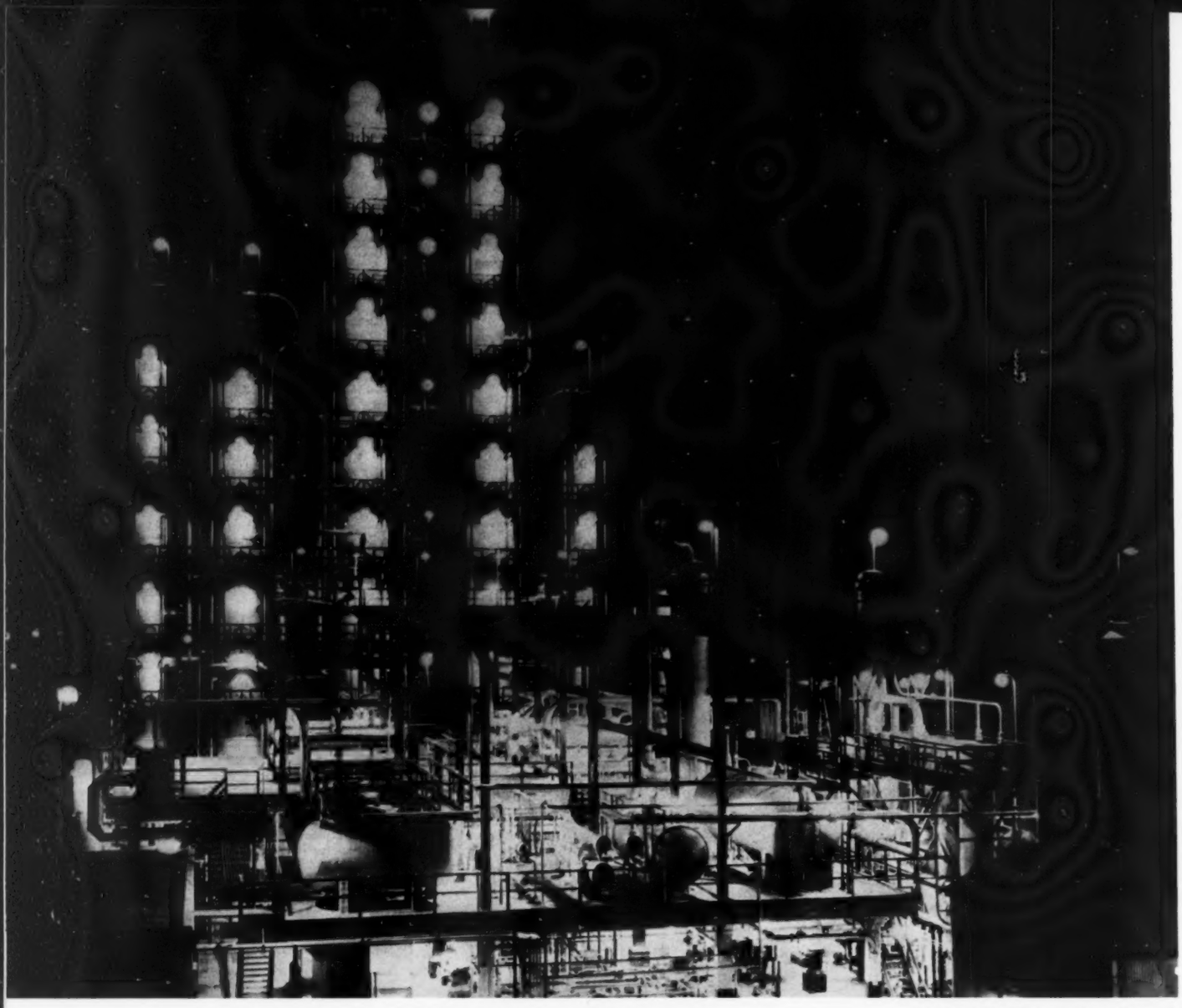


Below, left: Lummus thermofor catalytic cracking unit in Southeastern Texas.

Below: These plants, the largest ever erected in an oil refinery, are fluid catalytic cracking units which produce raw materials for synthetic rubber, 100-octane aviation gasoline and toluene for TNT. They were built by Standard Oil at its Baton Rouge refinery.







Night view of aviation gasoline plant in Texas Gulf Coast area.

Europe and made it clear that peaceful intentions could no longer be relied upon to avoid attack the President, in June, 1940, set up the Advisory Defense Commission to consider the steps necessary to implement the preparedness program then getting under way. An enlarged army, navy and air force obviously would consume more liquid fuel and consequently oil was accorded a place in the Defense Commission organization through the appointment of Dr. Robert E. Wilson to the post of Petroleum Advisor. Before 1940 the yearly consumption of petroleum products for military use had been on the order of 10,000,000 bbl. yearly. Additional requirements for ordinary gasoline and fuel oil presented no problem since both were in abundant supply but the creation of a substantial air arm meant a greater use of aviation fuel which called for some special consideration. At that time it may be well to remember any gasoline with an octane rating of 87 or higher was regarded as suitable for airplane use. In laboratory experiments pure isooctane (100 rating) had been produced but it remained a scientific curiosity since there was no place to use it.

With a small staff of assistants the Petroleum Advisor began a survey to determine the facilities available for the production of aviation fuel. This survey revealed that some forty refineries were in a position to produce gasoline of 87 octane or higher, that production was in excess of current demand and that stocks amounted to some 4,000,000 bbl. or nearly a year's supply as matters then stood. Following the advice of military authorities it was decided to recommend a 50 percent increase in capacity and the accumulation of a six month's supply in storage. On the strength of these improved prospects for demand several oil companies proceeded on their own initiative to construct high octane plants, a very improtant move as later events demonstrated.

With the enactment of the lend-lease law in April 1941 it became evident that a greatly increased demand for aviation fuel would follow inasmuch as it was more urgently needed by the nations fighting against the Axis than almost anything else in the entire category of war materials and since it now could be obtained on

One of the country's smaller but thoroughly mod ern refining plants which is working at ful capacity to supply the military machine. Offici OWI photo.

credit instead of for cash as formerly. One of the urgent problems confronting the refining industry in May 1941 when the President declared an unlimited national emergency and appointed Harold L. Ickes as Petroleum Coordinator was the expansion of aviation fuel production.

In establishing the office of Coordinator the purpose in view as defined by the President was to provide for the development and utilization with maximum efficiency of the petroleum resources of the country and the making of petroleum products available to meet military and civilian needs. Up to that time the petroleum industry had been able to respond to all demands as they arose. It still was in a position to undertake further expansion but the limitations placed upon the use of steel and other structural materials made it necessary to have the authorization of the federal government in order to erect new plants or enlarge old ones. Moreover it was recognized that private capital could not be expected to invest in plants erected solely for war needs and turning out products for which there

***Above:** Blending agent which gives high octane value to aviation gasoline is made in this alkylation section of the Standard Oil refinery at Baton Rouge.*

***Extreme left:** Partial view of Sun Oil Company Houdry plant for the production of aviation gasoline.*

***Left:** Alkylation plant at the Los Angeles refinery of the Union Oil Company.*

***Below:** Vacuum rerun unit of the Gulf Refining Company.*

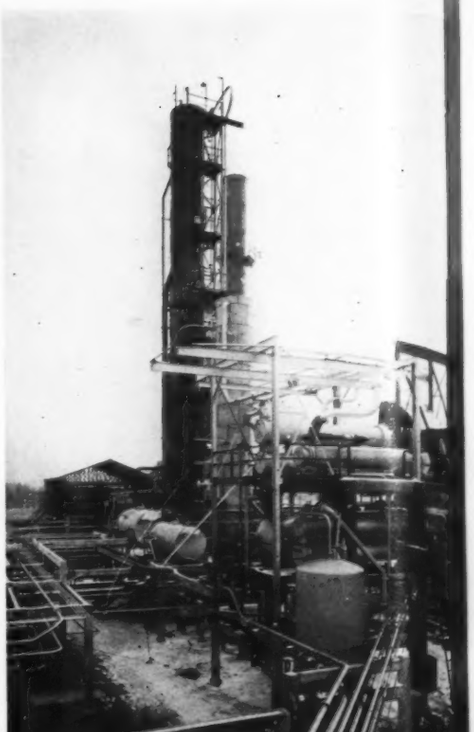
might be no demand after the war's end. Therefore the government prepared to finance construction undertaken solely for war purposes. A third very practical consideration was that in order to meet wartime conditions it was necessary to pool oil company resources and to combine activities in ways that would have been illegal if adopted on the initiative of the companies themselves but which could be sanctioned if undertaken on orders of government officials.

Coordinator Ickes promptly set up an office staffed by able men drawn from the ranks of the oil industry and created an advisory body representing all branches of oil trade activity. From the beginning the Coordinator made it clear that it was his intention to work with the members of the industry and not to domineer over them. A Division of Refining was established in the Coordinator's office under the direction of Wright W. Gray. Consistent team work between the Refining Division and the country's refining experts and among the latter has been responsible for the outstanding results attained. One of the early steps contributing to these results was an agreement for the exchange of technical information among oil companies and engineering firms, and authorization of the use of patented processes without the customary requirement of license fees or royalty payments.

Intensive development of the high octane program dates from the organization of the petroleum industry centering in the offices of the Petroleum Coordinator. One of the first acts of Mr. Ickes after assuming office was to direct a request to the oil industry for a doubling of the output of aviation gasoline. Very shortly this was followed by another proposal for trebling the production. To determine how this could be brought about most speedily a survey of existing facilities was started and a series of conferences was held with all manufacturers of aviation fuel together with their engineers and technical experts. The ensuing discussions revealed that potential capacity was substantially above actual production and the oil companies themselves presented plans for the installation of new units capable of raising output a full 100 percent. This involved not only a certain amount of new construction but also securing additional supplies of suitable base stocks and utilizing light end products from refiners who were not themselves engaged in making aviation grade gasoline.

While the plans adopted in the period from June to November 1941 provided for a relatively large increase in the production of aviation gasoline they still aimed at limited objectives. Their purpose was to provide supplies sufficient for the country's air force then only beginning to approach its later lusty growth and, beyond that, to satisfy the requirements of the nations to whom the terms of the lend-lease law applied. It was taken for granted that this could be done without interupting the normal flow of motor fuel and other products to civilians within the country. In view of the strong probability that further expansion might be required the engineering staffs of the larger refining companies prepared plans for additions to existing plants and considered suitable locations for new ones that might be needed. The Refining Division of the Coordinator's office studied the situation of the smaller refineries and worked out tentative plans by which their light products could be brought together in combination plants to swell the output of aviation fuel. Many proposals for the more complete utilization of available materials were submitted and studied. At the same time members of research organizations and operators of pilot plants were hard at work seeking ways by which heavier products for which the demand was inconsiderable could be made to contribute materials to the production of high test gasoline. The pressure was on but it had not yet risen to a point where it taxed the resources of the oil industry or presented serious problems in the provision of plant equipment. By the fall of 1941 the production of aviation fuel was well ahead of current demand and new plant projects involving an expenditure of $150,000,000 were under way, some in process of construction and others still in the blue print stage.

Japan's assassin attack in the Pacific, forcing the United States into the war as an active combatant presented an entirely new set of conditions. It meant the building of a big army, a multiplication of shipbuilding activity and in particular a vast expansion of the nation's air force. The latter, superimposed on the growing demands of other members of the United Nations, called for an immediate and sweeping enlargement of the high octane program. High octane too had come to have a new meaning in the months since the war first started in Europe. Military authorities had learned by experience that no fuel below 100 octane rating would adequately serve a plane in actual fighting. High octane therefore meant 100 octane or higher. The oil industry was prepared to produce it but



Lummus-built catalytic cracking plant.

Australian troops gather gas drums dropped from a ship somewhere in New Guinea. The supply of gasoline is important to keep the vehicles of war in action.

it required of course a heavier draft upon the precious light products.

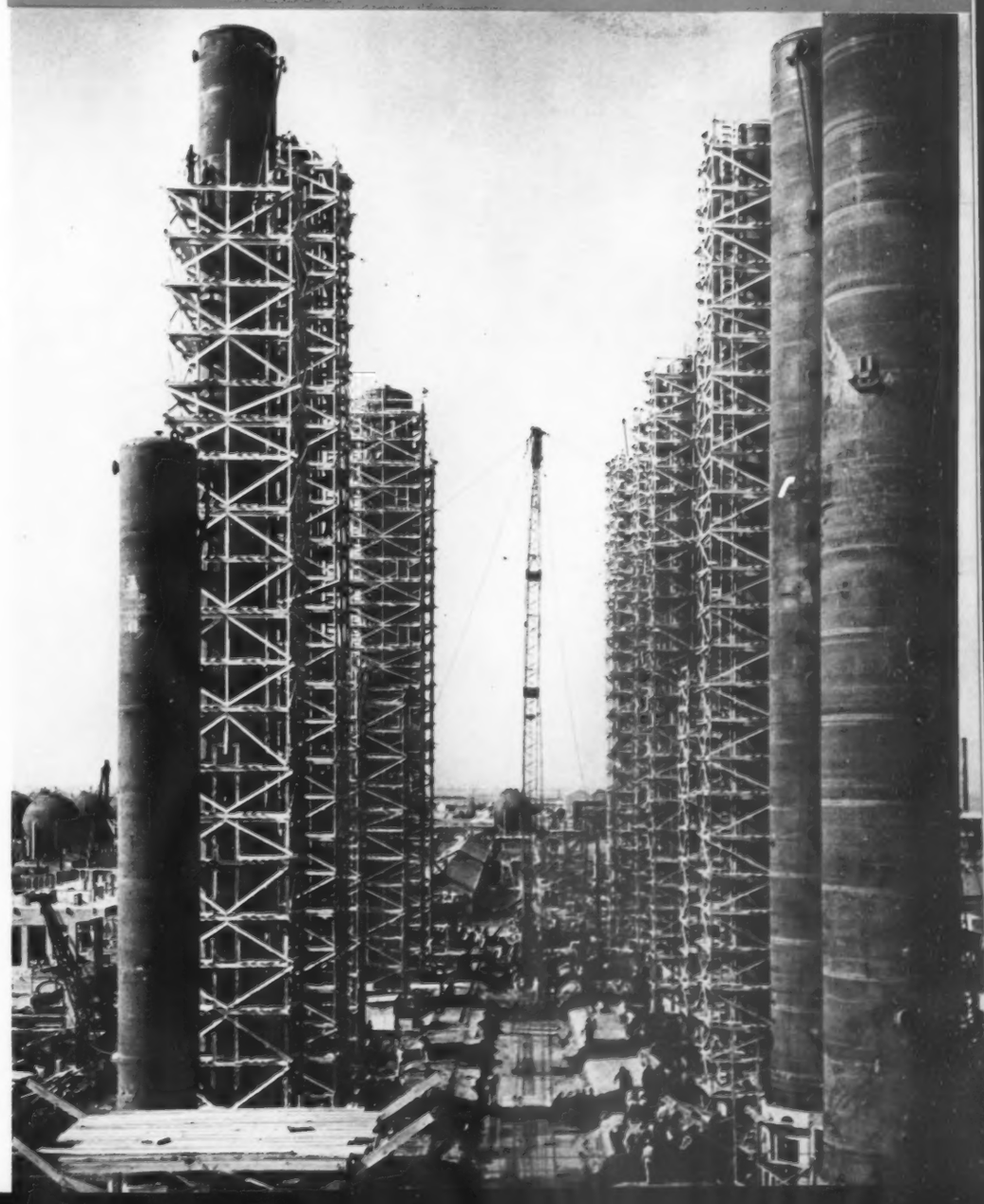
Following Pearl Harbor the refining industry entered on a period of intensive application that made its previous activities seem puny by comparison. Estimates of war requirements for high octane grew month by month until they reached astronomic dimensions in contrast with the carefully prepared plans of a year before. Refinery engineers and technical experts toiled day and night over designs and specifications. Engineering and construction firms searched frantically for men capable of fulfilling the orders that poured in on them. Not only in oil but in every other industry producing war products a vast expansion of facilities was called for. War plants were springing up all over the country. Planes, tanks, trucks, guns, shells and countless other instruments of war were needed in unlimited quantities and in a hurry. Demands for steel and other fabricated materials quickly outran supply and every agency charged with responsibility for any phase of war production was fighting desperately to obtain the materials to meet its urgent needs. The priorities system earlier in effect had broken down since priority orders freely issued by the Army, Navy and many government authorities were of no avail if the products called for were not at hand. Under the War Production Board a new system of controlling materials was set up and revised from time to time in the effort to arrive at a fairly equitable method of allocating the things imperatively required.

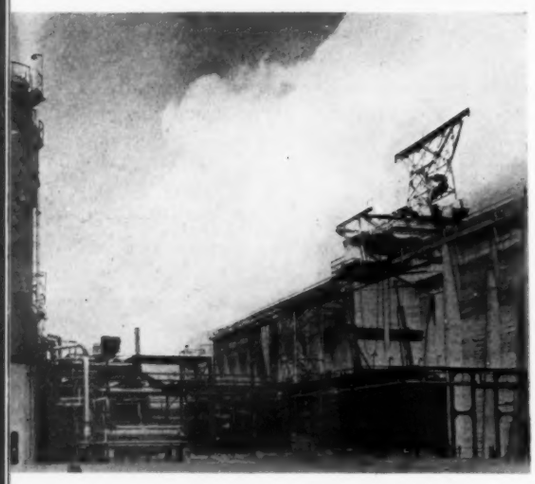
Since the structural materials and equipment necessary to refining installations could only be released by the War Production Board all plans and specifications had to be authorized by that body after approval by the Refining Division of the Petroleum Administration. Likewise, since plants producing strictly war materials will face a doubtful future with the return to peace-time conditions the Reconstruction Finance Corporation, through its subsidiary Defense Plants Corporation, undertook the financing of many of these plants. In spite of all obstacles the program has moved forward with astonishing speed and efficiency. Actual production by many completed plants has surpassed the estimates of their projectors and the supply of high octane gasoline has kept ahead of war demands despite the repeated multiplication of these requirements. It was recently announced that within the next few months 120 plants will be engaged in the production of high octane gasoline. Of these a majority are new plants or new units installed in previously existing plants but a substantial number represent conversions of plants formerly engaged in the making of ordinary commercial motor fuel. The investment in these plants and in facilities connected with them approaches the half billion dollar level.

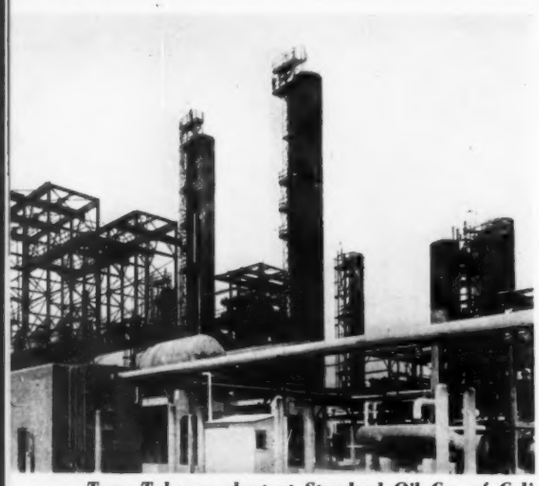
While the production of aviation fuel and its consumption for war purposes are military secrets it is no secret that the quantities far surpass anything heretofore envisioned in the history of the industry. An inkling of the extent to which aviation fuel is being employed to keep the nation's —and other nations'—air fleets in constant motion against the enemy is provided by a recent OWI statement that one segment of the Mediterranean air force alone consumed 400,000 barrels of high octane gasoline in fifteen days of bombing activity. Add to this the hundreds of squadrons operating on other fronts, some of them flying much greater distances, the gasoline requirements of the ferry command flying thousands of planes across the oceans and the still greater amounts employed in training the growing army of young pilots who are preparing for the grim business of war at camps scattered throughout the land and on overseas stations and some conception may be formed of the collosal scale on which this single petroleum product is shaping the course of the war and leading the way to final victory. Before the final chapter is written it is anticipated that the consumption of aviation fuel alone will equal the entire gasoline requirements of the country up to the time of World War I.

The high octane program is not completed nor will it be until the end of the war is clearly in sight. The vital part played in the conflict by aerial operations though grudgingly acknowledged in some quarters at first is now fully realized. As the air fleets of the United Nations grow in numbers, power and flying range more and more high octane gasoline will be required and more plants for its production will be erected. Only last month new contracts were placed for construction that will add greatly to the country's productive capacity and this procedure will be repeated at frequent intervals. Some of these are new locations selected to serve growing needs in specific areas but from this time on the major additions to facilities probably will consist of new units added to plants

Towers of the Neches butadiene plant. Photo courtesy The Lummus Company.







Top: Toluene plant at Standard Oil Co. of California refinery.

Center: Prior to Pearl Harbor this was the largest plant in the world making 100-octane gasoline. Built in 1931 at Standard Oil refinery, Baton Rouge, it first made lubricating oil by the hydrogenation process.

Bottom: The two large towers shown in this photo are deisobutanizers. Towers are 150 feet high with a diameter of 11 feet.

already built and in operation. In this way a greater economy in the use of critical construction materials will be possible.

Although the provision of facilities for the production of vast quantities of high octane gasoline has been a central and most important feature of the refinining industry's transition to a war footing it is only one of many changes from normal peacetime operation. One of the difficult problems placed in the lap of the refining industry was that of filling the gap in the rubber supply resulting from the Japanese conquest of the East Indies and the Malay States. Rubber is a necessary part of modern war equipment as well as an essential factor in the industrial economy of the home front. Failure to replace the 500,000-600,000 tons annually imported by the United States, of which more than 90 percent came from the Far East would have been a national disaster. The only possible means of replacement was through the production of what is conveniently but erroneously called synthetic rubber, in reality a substitute for the natural product.

It was known that petroleum could supply the main ingredients for the making of a satisfactory so-called synthetic rubber. A number of years before Standard Oil Company (N. J.) in acquiring from German interests the rights to a hydrogenation process for oil had included in the purchase the privilege of making Buna rubber. In its own laboratories the company worked out certain improvements and offered to license the process to rubber manufacturers. Other companies had devised processes of their own but there was no large-scale synthetic commercial operation because it was not possible to compete with the natural product. As far back as 1932 the Army and Navy Munitions Board declared rubber a strategic material and later recommended the development of a synthetic industry to assure military supplies. In 1940 a small start was made when two companies began the erection of plants for the recovery of butadiene from petroleum and in 1941 the government authorized the construction of four plants to manufacture synthetic rubber with a combined capacity of 40,000 tons.

When the United States was plunged into the war the urgency of providing rubber equivalents became imperative and preparations were rushed for the provision of plant capacity sufficient to meet the entire requirements of the country. As the most immediately available source of the materials needed for the production of Buna rubber, which was the type selected as best adapted to most uses, the refining industry was asked to construct plants for production of the required butadine and styrene while the actual manufacture of the rubber was turned over to the rubber companies who naturally possessed the technical knowledge and had the experience needed for this work. Later on it was decided to employ grain alcohol for part of the required production but the oil industry still carried the bulk of the load.

These plants, except the ones originally built by the oil companies on their own undertaking, were financed by Rubber Reserve which also contracted for the purchase of their entire output. Thirty-four plants with a combined capacity of over 800,000 tons were authorized during the first six months of 1942. Of these 16 utilized petroleum as their source of supply while seven others depended upon alcohol. Although some modifications have been made in the program laid down last year and the struggle over allocations of structural materials has led to some heated exchanges among Washington officials the men of the oil and rubber industries have gone steadily ahead with their part of the job. As a result the new plants are coming into operation; synthetic rubber is being turned out in rapidly increasing volume and the latest report of Rubber Director Jeffers is that 1944 will see the rise of production to a level that will satisfy all war and war production needs even though civilians may be forced to wait a little longer before equipping their cars with new tires.

In two years an entirely new industry has been brought into being, equipped, supplied and put into operation on a national scale. Not only has it averted a disaster that might have lost the war; already members of this new industry are pointing out the superiority of their product to that derived from slow growing tropical trees, its greater adaptability to many specialized uses, and are predicting confidently that if economic forces have free play America need nevermore depend upon distant sources of supply for the bulk of its rubber consumption which is greater than that of all the rest of the world put together. The investment in plants already built or building runs to hundreds of millions of dollars but its value to the nation cannot be expressed in terms of money.

Although the vastly expanded needs for aviation fuel and the creation of a great synthetic rubber industry have been responsible for the greater part of the huge construction program of the past two years petroleum has been called upon to render many other forms of service in connection with the war. One of these that is of special importance is the production of toluene, essential to the manufacture of powerful explosives. American oil men have the satisfaction of knowing that they have a direct share in making possible the hail of destructive bombs that has descended upon enemy fronts and industrial areas in recent months. Other products for which the war has created a heavy demand requiring the expansion of existing facilities are high grade lubricants, various chemicals derived from petroleum, petroleum coke, wax and asphalt.

In its conversion from normal peacetime procedure to all-out participation in an all-out war the petroleum industry has written a record that would be deemed impossible save for its actual accomplishment. The physical feat of providing and putting into operation a billion dollars worth of plant and equipment is but the outward symbol of changes and progress in technical methods and processes that extend to every part of the industry. Its part in the fight for freedom is being written in flaming letters by swarms of planes from Sicily to Tokio, in the crash of monster bombs upon enemy strongholds, by the pulsating course of thousands of ships across all the seven seas and in the steady march of the armored might of the United Nations toward the sure goal of Victory.

WAR TIME EVOLUTION

Brings Many Changes in Oil Refining

By Dr. O. W. Willcox

Great Increase in Quality and Power of Aviation Fuel, Development of Many Additives and Notable Improvement in Catalytic Processes Are Among Outstanding Results Attained—Progress from Complex to Simple Methods.

AN outstanding characteristic of contemporary petroleum refining technology in the United States is a condition of flux, in which new discoveries and inventions succeed and supersede one another with disconcerting rapidity. It has been said that under the stress of war-time demands upon them the refining technologists have learned more about oil refining in the past two years than in the whole of the preceding decade. One commentator has estimated that the improvement in refining methods has been twelve-fold.

This spurt of technological advance is due to the exigencies of the greatest war in which this nation has ever engaged. In times of conflict men must think fast and act speedily. Every man must now be a defender of his country and fight for it with all means within reach. The more and the better the means that can be thrown into the struggle the sooner will victory be achieved. Less attention must be given to profit and more to national service in production of the engines of defense and offense. Old techniques that did well enough in peace-time must be scrapped because they do not serve new demands for enormous quantity and superlative quality. Under this driving need for new levels of quantity and high degrees of quality, all departments of the petroleum refining industry have undergone and are still undergoing an evolution that in many cases is revolutionary.

In meeting the demands which the war has thrust upon them the refinery technologists have been required to create a substantially new industry for the production of aviation gasoline, and a wholly new industry for the production of materials for conversion into synthetic rubber. Of scarcely less importance is a new industry for the production of synthetic toluene for conversion into the TNT that is bestowed upon the enemy by our artillerymen and bombardiers.

Fundamental to all of these new industries is the art of cracking crude petroleum; or, in a more general sense, the art of subjecting pure or mixed petroleum vapors to a heat treatment designed to produce a certain desired result. Much of the new knowledge gained by the refinery technologists relates to improved methods and apparatus for applying these heat treatments.

At the time the industry was called upon to gear itself to the war effort the principal object of refining was to produce gasoline and Diesel fuel for various types of automotive vehicles then in common use, including airplanes that were mostly for commercial transportation; the heat treatments employed at that time were mainly such as would furnish the amounts and qualities of automotive fuels required for these purposes.

The war brought new demands for both quan-

Thermofor catalytic cracking unit in Eastern Texas. Photo courtesy The Lummus Co.

tity, and quality with special emphasis on quality. On the quantity side were the motive power requirements of an army of eight million or more men, of thousands of tankers, transports and fighting ships, of 50,000 or more airplanes.

To meet these demands there was a large but not too abundant supply of crude oil; it was soon apparent that the refiners would have to extract the utmost utility from every barrel, without waste. On the quality side were demands for products of new and very superior grades, especially in aviation fuel and lubricants, and for new and unfamiliar products out of which to fabricate synthetic rubber for military and civilian use. Overhanging the whole task was the matter of time, which would not wait, neither would the enemy. All together, the situation required a vast expansion of plants and the discovery and mastery of new working methods.

On the strictly technological side the problem required mainly a far-reaching revision of the industry's systems of heat treatment of petroleum vapors, beginning with the initial operation of pyrolytic decomposition, or cracking, of which there are two familiar divisions, the purely thermal and the catalytic. At the start of the emergency by far the larger portion of crude petroleum was processed in the refineries by the thermal process, in which the crude oil was decomposed at high temperatures in pipe stills of various designs. While thermally produced gasoline provides a fair base for ordinary motor fuel and is still a major reliance for the propulsion of civilian and military vehicles that operate on the ground, this process alone is hopelessly inadequate to furnish either the quantity and especially the quality of gasoline needed for airplanes.

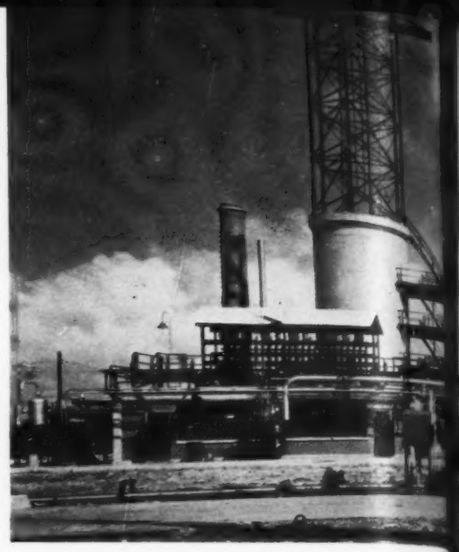
The thermal cracking process has therefore been technologically relegated to secondary importance as a means of obtaining high quality wartime petroleum products. However, it has undergone a certain evolution that enables it to contribute important intermediate products. Thermal cracking is a fair source of olefins that are needed as raw materials for both aviation and synthetic rubber. For this purpose the pipe still used in thermal cracking is improved upon by the regenerative furnace or "stoves" of the type long used in metallurgical industries. With such a furnace heavy naphthas can be cracked to produce butadiene in 52 percent yield; or mixtures of by-products such as ethane and propane may be cracked to give mixed ethylene, propylene and benzene to be worked into aviation gasoline. The regenerative furnace is also a fairly good means of obtaining acetylene, and in general is superior to the pipe still as a source of unsaturates.

The main burden of meeting the special demands of wartime has fallen upon the catalytic process. At the beginning of the emergency the only important representative of this process in the cracking art was the well-known Houdry process. In this process the petroleum vapors are heat-treated in a large chamber containing a fixed bed of granular catalyst; in time the grains of catalyst become fouled with carbon and the process has to be interrupted to purify them. The especial merit of catalytic cracking is that it gives a larger yield of products within the gasoline range, and these products have higher numbers on the octane scale of gasoline quality. An immediate task of the refining industry was to expand capacity for catalytic cracking so as to meet demands of the military, and in the course of this expansion the catalytic cracking process entered a period of evolution that is still continuing, both as to form of the apparatus, and, more importantly, the character of the catalyst.

On the apparatus side, there was a shift from the fixed bed of catalyst used in the Houdry process to the movable bed as used in the Thermafor process, and to the "Fluid" catalyst sponsored by the Standard Oil Company of New Jersey. This constructional shift has been motivated by various considerations, involving investment cost, time required for installation, availability of critical materials, and other circumstances that at the moment favored one against the others. A main argument for the movable as against the fixed bed is that the fouled catalyst can be regenerated in a vessel separate from the reaction chamber, and in a certain sense the cracking process then becomes continuous instead of intermittent.

More important even than improvement in the form of apparatus is the evolution undergone by the catalyst itself. The special function of the catalyst is to control the pyrolytic decomposition of the petroleum vapors that in the thermal process runs more or less wild and results in the production of low grade gasoline and undesirable by-products which represent a good deal of waste. In other words, the thermal cracking process is wasteful of time, crude oil, and plant capacity, and is incompetent to meet the imperative demands of wartime for quantity and quality. In contrast, the catalyst process is controllable so that a large proportion of the raw material is turned into valuable war products, and this control is so flexible that the proportions among these war products can be varied according as the momentary demand for one is greater than for another.

It has turned out that just as one form of catalytic cracking apparatus may be more convenient than another, so one kind of cracking catalyst may be more efficient than another. Efficiency in a catalyst means ability to transform a given quantity of charging stock into a maximum proportion of desired products in a minimum of time, thus saving plant capacity, making raw material "go farther," and supplying the war machine with more barrels of finished product per day. Consequently the ingenuity of the apparatus designers has been running a friendly race with the resourcefulness of the chemists who specialize in the chemistry or catalysis. The



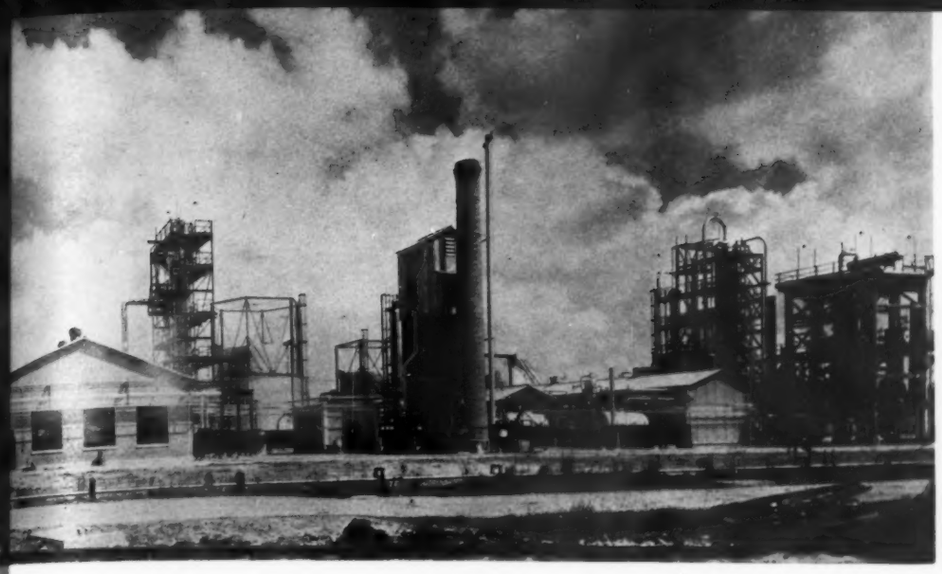
Iso-octane plant in Southeastern Texas incorporating hydrogenation and selective polymerization.

work of the construction engineers can be seen in the plants they equip, but the chemists do their work under the molecular surface of things and produce their catalysts by methods known only to themselves. Bystanders know only that new and more efficient cracking catalysts are appearing in the industry, and where and when this evolutionary cycle of improvement in catalysts will end no one can yet say. Sometimes the chemists produce a more powerful catalyst before plants designed to use the previous best one have been finished, and the construction engineers have to modify their plans accordingly.

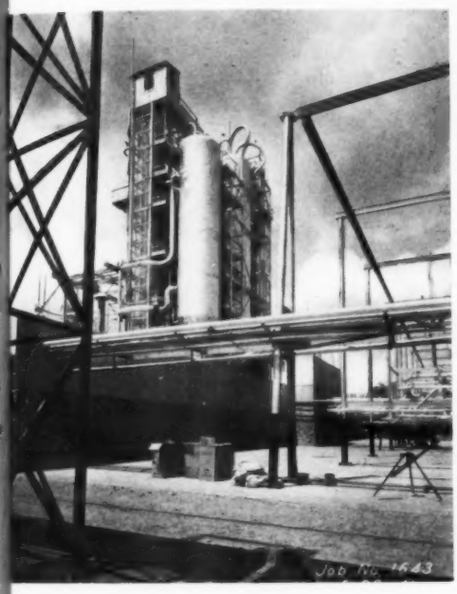
At the moment of writing a peak of efficiency seems to be ridden by the "bead" catalyst sponsored by Socony-Vacuum. It is claimed for this catalyst that it will produce a gasoline that has more power than any 100 octane number gasoline now (or at that time) in use. Perhaps this achievement may be topped before these lines appear in print.

Not only is there a continuous evolution that brings forth more efficient cracking catalysts, but the methods of using cracking catalysts is undergoing an evolution toward a more understanding exploitation of them. To do its best work a cracking catalyst must be provided with conditions of temperature, pressure, rate of feed and time of reaction most appropriate for it. These conditions must be found out by the cut and try method; it has happened that the experimenters have hit upon a certain combination of conditions under which a new catalyst shows itself to be better than the previous best, and later find a new combination which leads to the eclipse all its previous performances.

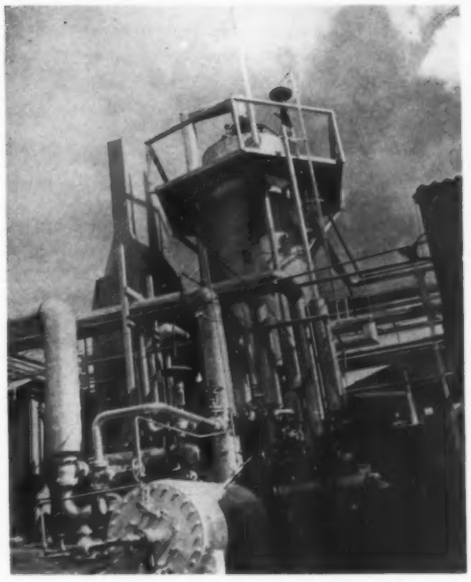
An example of this is a method which has been given the unrevealing name of "Houdry adiabatic process," which to a physical chemist suggests an application of the laws of thermodynamics governing the accumulation and disposition of the heat of the reaction. Sweeping claims made for this process are breath-taking: "The gasoline thus produced is so good that no existing engine can fully utilize it; it is as far ahead of present



First of thirty new catalytic cracking units designed to produce both 100-octane aviation gasoline and butadiene for synthetic rubber. It was built by Standard Oil Co. (N. J.) as part of its extensive war production program.



Naphtha polyform plant recently completed in Gulf Coast refining area.



First of its kind in the warld. Section of an adiabatic cracking unit at a Sun Oil refinery. A development of Houdry research which produces aviation fuel.

aviation gasoline as present aviation gasoline is ahead of present third grade gasoline; its principal use now is as a diluent to upgrade inferior gasoline to present aviation standards." Full use of this product must wait. It is now late in the day to start converting existing aviation gasoline plants to work by the adiabatic process, and the war cannot be recessed until the engine builders are able to utilize all this new wealth of octanes. The producers of aviation gasoline must therefore continue for the moment to follow through with the line they have been pursuing and let the airplane and engine builders catch up when they can.

This line has been consistently aimed at putting more octanes into fighting grade aviation gasoline, and many ways of accomplishing the purpose have been uncovered. The pre-Pearl Harbor method was to prepare the best possible grade of gasoline, and add to it blending agents and tetraethyl lead to boost the octane number up to 100. Great improvements of this method have since taken place. The evolution of ways and means of obtaining blending agents for aviation gasoline does in fact constitute one of the most active phases of contemporary oil refining technology. The need for blending agents arises from the fact that ordinary gasoline is mostly a mixture of straight chain hydrocarbons that have low octane numbers. On the other hand, hydrocarbons with molecules that have one or more branches (iso compounds), or have ring-shaped molecules (aromatic hydrocarbons), are found to have higher octane numbers.

The octane rating of a gasoline thus largely depends on the relative proportions of straight, branched and ring-shaped molecules in it. Catalitically cracked gasoline is superior to thermally cracked gasoline because it has fewer long, straight-chain molecules. For that reason catalitically cracked gasoline is now the preferred foundation or base stock out of which to make aviation gasoline by compounding it with whatever blending agents are at hand. First to come into consideration are the light hydrocarbons, particularly the iso compounds found in natural gasoline. The supply of these being limited, it is necessary to manufacture additional quantities of high octane material out of low grade or salvaged refinery products.

Many methods for manufacturing high grade out of low grade products were known before Pearl Harbor; since then these methods have been expanded and new ones added. There are six general methods in use for obtaining high grade blending agents for supplementing the deficiencies of cracked gasoline, whether thermal or catalytic. These are (1) polymerization, (2) hydrogenation, (3) dehydrogenation, (4) alkylation, (5) isomerization, (6) cyclization. Alternative names for these general methods are sometimes met with: polyforming, hydroforming, reversion, isoversion, isomation, cycloversion. Whatever the name, the object is to produce a blending agent for up-grading base stock to and beyond 100 octane number. At the bottom of each variant of these general processes for obtaining blending agents is now a catalytic process, which may employ a catalyst invented before Pearl Harbor or a recently developed one. Much has been said in praise of the accomplishments of American petroleum researchers, but it seems not to be generally realized that the greatest advance in oil refining machinery and technology has come through the discovery and use of old and new catalysts. Aside from the still numerous skimming and thermal cracking plants, nearly all recently built refineries have one or more catalyst installations, and it is generally more. There is a catalyst for nearly every conceivable operation by which low grade petroleum products may be up-graded. The Phillips Petroleum Company, for instance, has 30 types of catalyst processes employing fifteen different catalysts now in actual or planned use for cycloversion, isomerization, alkylation, cracking, reforming, hydrogenation, dehydrogenation, polymerization, depolymerization, gum stabilization,

desulphurization, copper sweetening, and the manufacture of gas. Some of these Phillips catalysts are being manufactured and placed at the disposal of other oil refineries. Certainly it would seem that the modern refinery technologist does not now lack the tools he needs!

Polymerization and the various aspects of hydrogenation came into prominence during the earlier phases of the "race for octanes." The function of these processes is to transform the olefins that are produced in cracking operations into more satisfactory components of motor fuel. They still have their place as components of base stocks, but their relative importance in war-time conditions has diminished.

The times demand more and more powerful blending agents for up-grading base stocks for aviation purposes. The newer means of meeting this demand fall into three divisions: alkylation, isomerization and cyclizaton, of which the earliest to come into large use is alkylation.

By and large, the object of an alkylation process in the oil refining industry is to produce the hydrocarbon known as isooctane, or at least to produce a more or less pure mixture that approximates as closely as possible to the chemical and physical nature of isooctane. Isooctane is the octane which rates 100 on the old scale by which the anti-knock characteristics and power-giving qualities of gasoline have been measured. Not so long ago isooctane was produced by polymerizing certain olefins to make an octene which was then hydrogenated to isooctane. The chief disability of this process is the cost of the extra hydrogenation step, and a different approach was adopted. This is to take a C_4 olefin, such as butylene, and combine it directly with a C_4 paraffin such as isobutane; the produce is the C_8 paraffin hydrocarbon isooctane. This union of an olefin and a paraffin is akylation. The original alkylation process for commercial purposes was based on the use of sulphuric acid as the catalyst for effecting the union of butylene and isobutane. It started as a hot process and evolved into a cold process; lately it has undergone a further evolution by which hydrofluoric acid has replaced sulphuric acid as the catalyst. The reason for this evolution is the same underlying desire for greater efficiency and convenience. Besides the two acid alkylation processes there are one or more minor processes that use other catalysts.

For a large part of its raw material the alkylation process is dependent on another "new tool" of the oil refiner—isomerization. Isobutane occurs naturally in the gases of most oil and gas wells, and the exigencies of the situation have required the natural gas plants and the topping plants to recover every possible barrel of it for the aklyation plants. While a special emphasis is laid on the recovery of isobutane because of its scarcity, the natural gas and the topping plants are also required to recover the associated hydrocarbon, normal butane. This requirement has had evolutionary repercussions on another aspect of the refining art—the art of fractional distillation. Nowadays it is highly desirable to obtain individual hydrocarbons in as pure a state as possible, because chemical reactions and syntheses can be carried out with greater efficiency and precision with pure substances than with mixtures containing substances that are foreign to the purposes in view. Hence the distilling columns that are to be found in every oil refinery and natural gas plant have to be built to effect much sharper separations than in the pre-war days. Some of these columns are of unbelievable efficiency, and to attain this efficiency some have been built to record heights, reaching 150 feet in at least one instance.

The supply of natural isobutane from the oil and gas wells is insufficient to meet the enormous demand laid upon the alkylation processes.

There is a plentiful supply of normal butane, and since the war began processes have been evolved for converting butane into isobutane. This involves conversion (isomerization) of the straight-chain C_4 molecule into a branched chain C_4 molecule — a change in molecular shape without any change in the chemical composition of the molecule. The original commercial process for isomerizing normal butane to isobutane was a vapor phase process in which vapor of normal butane is passed over a fixed bed of catalyst, which in this case is solid aluminum chloride; the temperature of the operation is kept so that both the feed and the reaction products remain in the vapor phase. More recently the isomerization of normal butane has evolved into a liquid phase operation in which the aluminum chloride and the butane feed are dissolved in a special organic solvent so that all reacting materials pass through the operation as a continuous stream of liquid. Spent catalyst is removed and make-up catalyst is added without shutting down the process for a regenerating operation. This is one example of the general evolutionary trend that has affected numerous operations in oil refining and other divisions of chemical technology —the substitution of continuous in place of intermittent or batch processing. A more conspicuous example of this trend is the advent of the thermafor and the fluid catalytic cracking processes, with their moving catalyst beds following upon the original Houdry process with its fixed catalyst bed. However, in this connection it is not meant to imply that a movable catalyst bed is in all cases necessarily superior for cracking or treating purposes to a fixed bed.

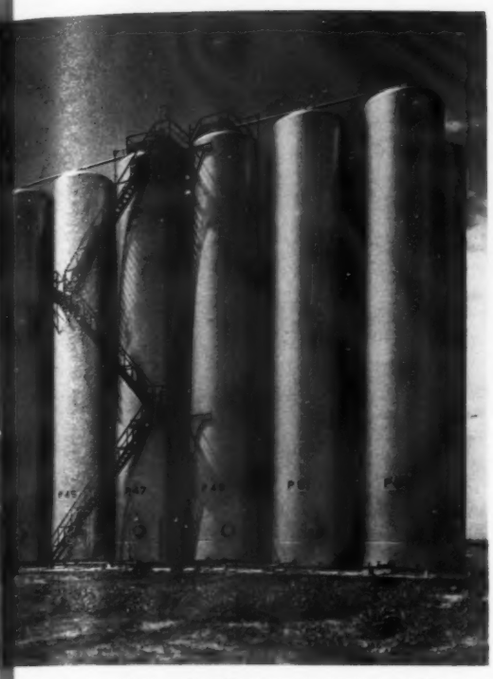
Though in the production of supplemental isobutane the isomerizing process is serving as an indispensable handmaiden for the alkylation processes, it has also been evolving on its own account, and has taken a turn that promises to usurp more or less of the field heretofore occupied by the alkylation processes themselves.

Normal butane (C_4) is only one straight-chain hydrocarbon that can be made into a branched chain without altering the chemical composition of the molecule. Pentane (C_5) can be converted into isopentane, hexane (C_6) into isohexane, heptane (C_7) into isoheptane, and so on up the line as far as it is desirable or practical to go. Whenever a straight-chain hydrocarbon is thus shortened and rounded by making it into an isomer its otcane number is increased. For many practical purposes it is not necessary to work on the pure or isolated straight-chain hydrocarbons; they can be treated in the mixed condition as they occur in ordinary gasoline. The resulting mixture of isomers is called an "isomate."

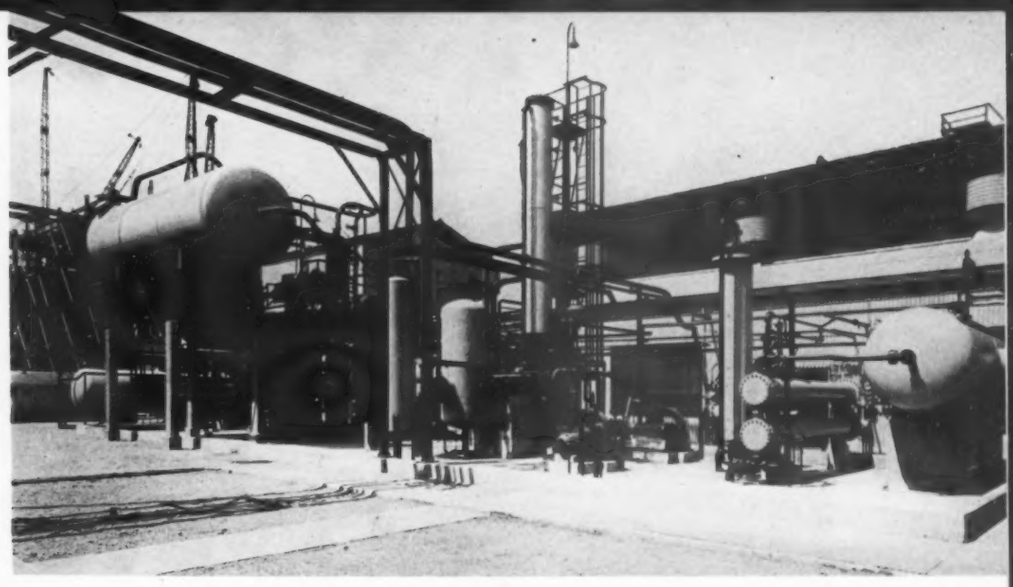
By this means a high grade aviation base stock may be obtained which will require less alkylate blending agent to bring it to fighting grade. In fact, the evolution of improved practice in producing isomate has considerably reduced the requirement for alkylate in the aviation gasoline program; one authority estimates this reduction as from 60 down to 30 percent.

Except for certain technical and economic factors of the moment, isomerization in its most advanced form might displace alkylation altogether. Alkylation is a two-stage process, in which it is necessary first to procure a supply of olefin and isoparaffin (both of which are reworked products), and then in a separate operation combine them to form isooctane, which has a theoretical octane number of 100. On the other hand, isomerization is a one-stage process. For instance, in a process developed by Standard Oil Company of Indiana, normal hexane as it comes from the superfractionator may be passed through a catalyst bed of aluminum chloride activated by hydrochloric acid and converted into dimethyl hexane, which has a much higher anti-knock quality than isooctane. This form of hexane which has two branches on the original straight chain was originally first produced by Phillips Petroleum Company in a two-stage process by decomposing a mixture of ethane and propane into ethylene, and then alkylating the ethylene with separately produced isobutane. The advantage of obtaining this powerful blending agent (neohexane) in a one-stage process is obvious.

The production of blending agents more powerful than isooctane is forcing a revision of the scale on which the anti-knock quality and energy content of a gasoline are measured. Formerly it was inconceivable that a gasoline could have an anti-knock quality greater than that of isooctane, which rates 100 on the octane scale. With the appearance of such isomated products as neohexane, a new scale was needed. The form of this new scale is not yet settled. Some are disposed to rate the higher grades as super-percentages on 100 octane; thus we meet with references to new products that have 110, 120 and even up to 142 percent higher octane values than isooctane. Others rate the newer blending agents by the number of cubic centimeters of tetraethyl lead that would be needed to bring



Butane plays a highly important part in the production of high test gasoline and in the provision of materials for synthetic rubber. This view shows a group of butane storage plants.



Naphthene isomerization section of one of the first of the new toluene plants.

isooctane to the same level. The reality of this greater power has been proved in small testing engines, and to a certain extent in airplanes on the fighting fronts which are flying farther and faster with heavier loads than ever before. But none of the big engines has yet been able to develop the full power which the small engines have proved to exist; the engine designers still have to learn how to use all the fuel energy which the refinery technologists are putting at their disposal. For the present, the use of these super-fuels is limited to the function of blending agents for upgrading inferior aviation base stocks.

Meanwhile, another technique for producing super-fuels has been evolving which promises to outdo both alkylation and isomerization in the fabrication of super-fuels. This technique may be globally designated as "cycloversion" and it has appeared in a number of varients. The function of cycloversion is to convert paraffinic hydrocarbons having straight chained molecules into the class of hydrocarbons called the aromatics, which have ring-shaped molecules. It was pointed out above that when a straight-chained hydrocarbon is isomerized by giving it a branched or more rounded structure its octane number is raised. In a manner of speaking, a branched molecule still has angles and corners, and this angularity is reduced to a minimum if the molecule is made into a perfect ring. Ring structure is characteristic of the aromatic hydrocarbons, so the production of aviation gasoline base stocks and blending agents rich in aromatics has become an important aim and has given rise to a new technology. One of the points of superiority of catalytic over thermal cracking is that the catalytically cracked product is richer in aromatics. By special processes the proportion of aromatics may be greatly increased, even to the point where the aromatics greatly predominate. This is the case with a new three-pass variant of the Houdry process (C.-T.-C. process) in which the best features of catalytic and thermal cracking are combined. It is also the case with the Phillips cycloversion process, which subjects naphthas or heavier fractions to the action of special synthetic catalysts. When these feed stocks are catalized in the presence of an excess of hydrogen the process is called hydroforming.

A special recent development of cycloversion is the synthesis of the aromatic hydrocarbon known as toluene. This hydrocarbon is produced by tying the C_7 straight hydrocarbon normal hexane into a C_6 ring to which the remaining carbon atom is attached as a methyl group. The success of the refinery technologists in producing toluene from petroleum removed a serious bottleneck in the production of trinitro-toluene (TNT), the principal high explosive that fills the shells that are being rained on the Axis. However, the swiftness of the changes that are occuring in the chemical technology of wartime is illustrated by the fact that TNT has been touched with obsolescence. Late news items reveal that a huge factory manufacturing TNT has been scrapped even before it came into full production, because of shifts in the character of explosives now required. What the new substitute for TNT may be has not been revealed, but it is a nearly safe guess that its base, if not its entire production, comes from the petroleum industry. Nevertheless, it has now been demonstrated that most if not all of the aromatics needed by post-war industry can be cheaply furnished by the oil refineries. What effect this will have on the coal-tar industry, heretofore the principal source of these aromatics, remains to be seen.

Besides imposing on the refining industry the necessity of evolving a great new art of fabricating automotive fuels, the war has laid on the industry the burden of providing the basis of a large new synthetic rubber industry. The groundwork for this industry in the United States was prepared largely through forehanded arrangements made by the Standard Oil Company of New Jersey. The most desired type of synthetic rubber is made from butadiene, a diolefin hydrocarbon found in cracked petroleum gases. The emergency made it necessary to evolve methods for procuring butadiene in enormous quantities as soon as possible; and, as seems to be a rule in the evolution of new processes in chemical technology, the first methods of making butadiene were clumsy and relatively inefficient. A rough and ready way is to subject petroleum vapors from ethane-propane to naphthas to severe thermal cracking and to isolate the butadiene from the cracked mixture by fractionation or solution. This is a crude method, but in view of the demand for speed it had to be and is still being used along with more rational procedures. One of these procedures is to manipulate cracking operations, particularly catalytic cracking, so as to produce the olefin butylene, which in a second stage is converted into the diolefin butadiene. The process of making butadiene from butylene received official approval as the main basis of the synthetic rubber industry, but immediately thereafter a two-stage Houdry catalytic process for catalytic conversion of butane (of which there is a large available supply) into butadiene was introduced. More recently the Houdry two-stage butadiene process evolved into a one-stage process, which besides its directness, makes an astonishingly small demand for critical materials.

In this case as in many others, the oil refining industry has followed the rule of evolving from the complex to the simple. Unfortunately, the simplification of the process for obtaining buta-

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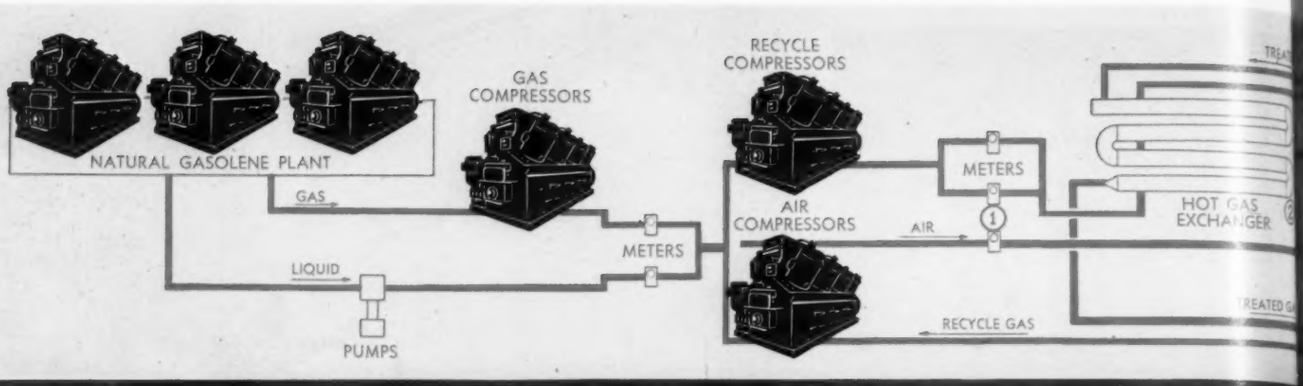

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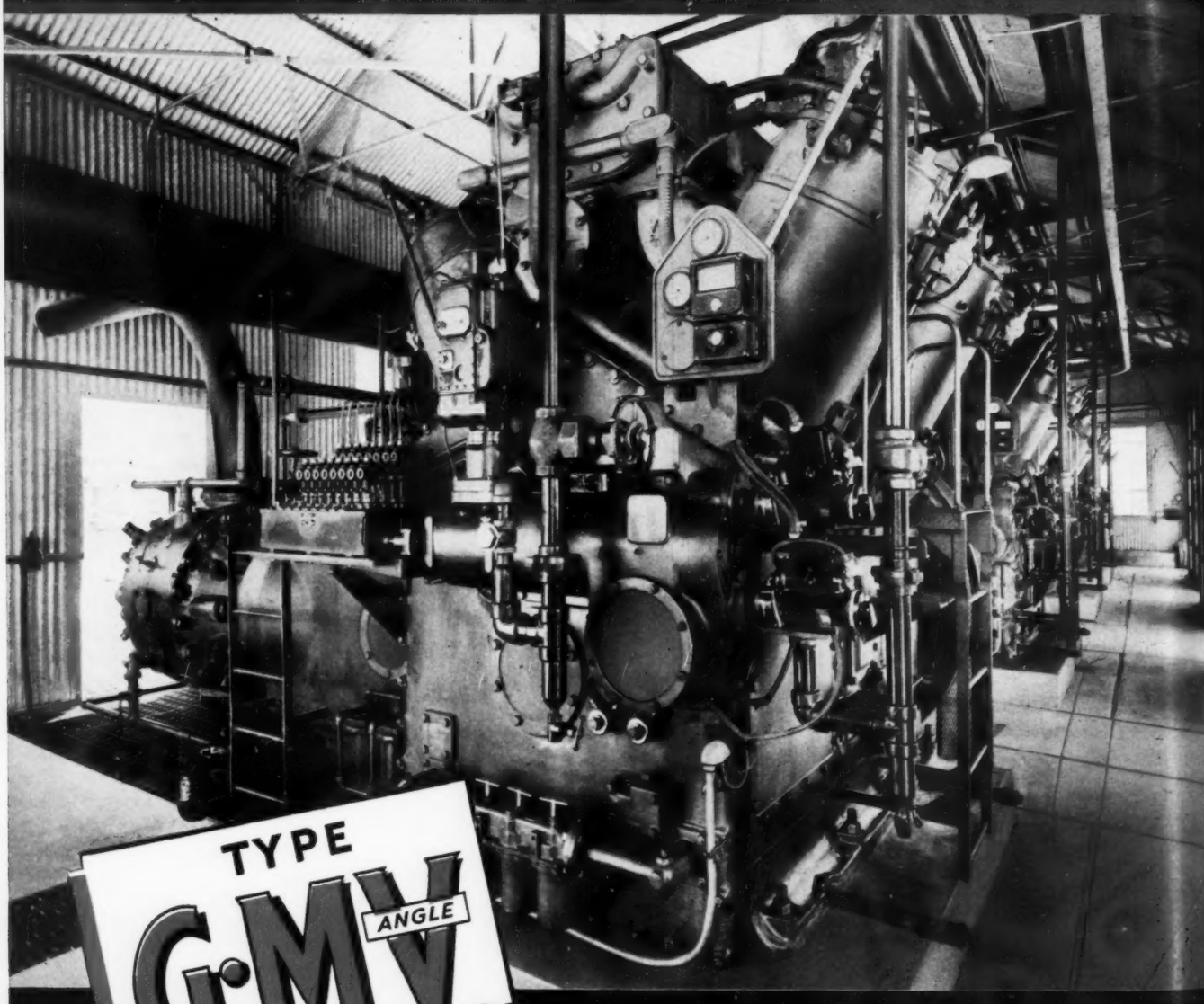

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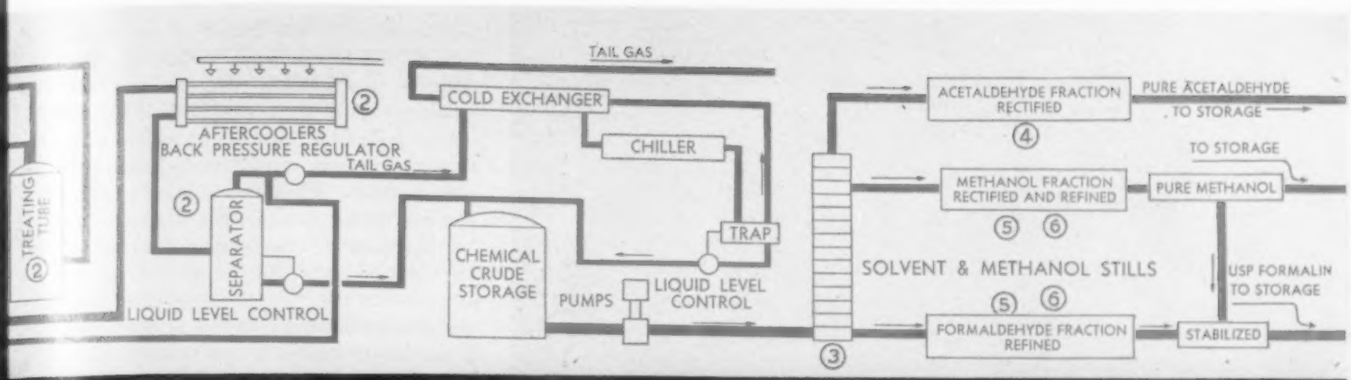

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Most modern type compressor is the G-MV — rugged . . . reliable . . . powerful — with a compact V-angle gas engine. Uniform flow rates, torque, and pressures are maintained by Cooper-Bessemer's unique automatic control. The G-MV is built to handle any gas. It is ideal for synthesis work and is available for early shipment.

At Left — G-MV's of the type recently installed in one of Cities Service Company's plants. G-MV's are now built in four sizes—400, 600, 800 and 1000 hp. They develop working pressures required for any process, high or low.

r *by* Cooper-Bessemer

MOUNT VERNON, OHIO AND GROVE CITY, PENNA.

Houston, Dallas, Greggton, Pampa and Odessa, Texas Tulsa Shreveport St. Louis Los Angeles Seattle, Wash.

Furnace and catalytic case of semi-commercial adiabatic cracking unit at a Sun Oil refinery. Adiabatic process is the latest and most important Houdry development.

Houdry Catalytic Operations at Marcus Hook

By this time all those who read the war news or listen to the radio commentators will have come to understand the high importance and scope of the war in the air, particularly since the Allied High Command has embarked on an effort to achieve victory by mass bombardment of the enemy's factories and transportation systems. Success in this momentous undertaking will depend on the ability of the petroleum industry at home to supply aviation fuel in quantity and quality that will enable vast aerial squadrons to reach their targets, and to outmaneuver and outfight the enemy opposition.

The American petroleum industry is acquitting itself handsomely in both aspects of the task that has been laid upon it. As to quantity, no exact figures are to be given out, but the censors have allowed the statement that consumption of aviation gasoline in a single day's operations of our air force during the North African campaign has at times amounted to 1,250,000 gallons. Add to this the undoubtedly great quantities of American aviation gasoline that at the same time were being consumed over western Europe, in the Southwest Pacific, on the China front, on the Russian front, by the airplane ferry service to all quarters of the globe, by the submarine patrols and by the flying schools, and the sum must be a staggering one. Yet the American producers of aviation gasoline have not yet attained full stride; new plants for the manufacture of this sinew of war are continually coming into operation. The enemy is being overwhelmed not only by the quantity, but also by the quality of American aviation gasoline, which nothing the Axis has produced can quite match.

Aviation gasoline can be and is being made by a number of processes, chief among which is a group of procedures known as the Houdry catalytic process. The importance of this process to the war effort is indicated by the fact that up to the early part of 1943, about 90 percent of all catalytically cracked high octane aviation fuel was coming from Houdry plants.

The first Houdry plant to come into full scale commercial operation was located in Marcus Hook, Pa., and began operation about 1937 with a unit which is called the 11-4 plant. Since then other Houdry units have been added at this refinery, and in the six ensuing years the process has undergone a series of changes and improvements. The history of this development comprises two periods which are separated by the outbreak of World War II in 1939. Before that date the operators of Houdry plants, like other refiners, were chiefly concerned with production of more and better motor gasoline; after it, the production of more and better aviation gasoline became the dominant purpose, although it is still essential to produce motor fuel in considerate amounts.

The original Houdry catalytic cracking unit at Marcus Hook, plant 11-4, was what is called a 6-case unit, that is, it had six vessels for holding the solid catalyst material. In the regular course of operation petroleum vapors at a temperature of about 850° F. would be passed through two of these cases for cracking, two others would be undergoing a process of regeneration in which carbon deposited on the catalyst particles in a previous operation is burned off, and the other two would be undergoing purging in preparation for a new cycle. Production of catalytically cracked gasoline would be continuous, as two of the six cases would always be "on stream." The mechanical arrangements for shifting from one phase of operations to the next are one of the marvels of the art of process control, and have been extensively described by writers in World Petroleum and other journals. Equally noteworthy are the arrangements for controlling the heats of reaction by means of a circulating stream of molten salts.

Plant 11-4 was designed to work principally on heavy reduced crude oil, the so-called residues that are left from topping off the lighter and more valuable hydrocarbons. At that time it worked mostly as a "one pass" system, from which the cracked products passed through the usual routine of fractionation and stabilization

and from which there was finally obtained a motor gasoline superior in both quantity and quality to the product turned out by the conventional thermal cracking process.

Similar Houdry plants were soon in operation at other refineries. At Marcus Hook another Houdry unit, plant 12-3, was put up. This unit was larger, having 12 cases to operate on reduced crude. In connection with this plant another phase of the Houdry process was materialized. This amounts to a second pass (retreating) in which the catalytically cracked gasoline produced from reduced crude in the first pass is again vaporized and sent through a 2-case unit to be recracked under somewhat milder conditions. This treatment raises the already good quality of the catalytically cracked gasoline by further modifying the molecular structure of various constituents of the mixture, removing or reducing the sulphur content, decreasing the tendency to gum, improving the color and raising the octane number.

The next addition to the Houdry facilities at Sun's Marcus Hook refinery was a 3-case reforming unit erected in connection with plant 12-3, in which a high-octane gasoline could be produced direct from coast naphtha boiling up to 525° F. end point.

In the meantime the market was readily absorbing catalytically cracked gasoline, and another unit, known as plant 10-3, was installed to produce motor fuel from gas oil. This plant, though having the same number of cases (12) as plant 12-3, is the largest of all, and is turning out the bulk of the catalytically cracked gasoline produced at Sun's Marcus Hook refinery. At the same time the 3-case reforming unit in connection with plant 12-3 was taken off reforming and put to work as a second pass treater.

This 10-3 unit is noteworthy as the largest catalytic cracking plant in the world. The amount of aviation gasoline it is capable of turning out is not for publication. It was put in operation in December, 1940. Like the other Houdry units at Marcus Hook at that time it was designed for the production of high octane motor gasoline, and continued in that service until February, 1942, when it was completely converted to the manufacture of 100 octane number aviation gasoline. It has been given out that the cost of constructing this plant was $4,600,000. Its 12 cases contain a total of 250 tons of catalyst material. Air for regeneration is furnished by two turbo compressors circulating 40,000 cubic feet of air per minute. To regulate temperatures within the cases over 36,000 gallons of molten salt are circulated per minute. In the process of regenerating the catalyst more than 100 tons of coke are burned off the particles; this heat is used to generate 120,000 pounds of high pressure steam per hour.

The control room is the show place and nerve center of the unit. Here gauges and recorders show temperatures, pressurers, flows of oil, salt and vapor in all parts of the unit. The panel board has at its center the cycle timer which operates the various valves, keeping oil passing continuously through certain cases and air continuously passing through others for regeneration, with the necessary purging intervals between. The lights on the board show which of the motor operated valves are open (red) or closed (green), indicating exactly what is going on in each of the cases. The lights of a single case may be watched, showing the case with oil going through, the closing of the oil-in and oil-out valves and the evacuation of the remaining oil vapors from the case. Air-in and air-out valves automatically open, and regeneration proceeds. Then the air valves are closed. After evacuation of the air, the case returns to the "on stream" period completing a cycle. This process is repeated 48 times a day on each case.

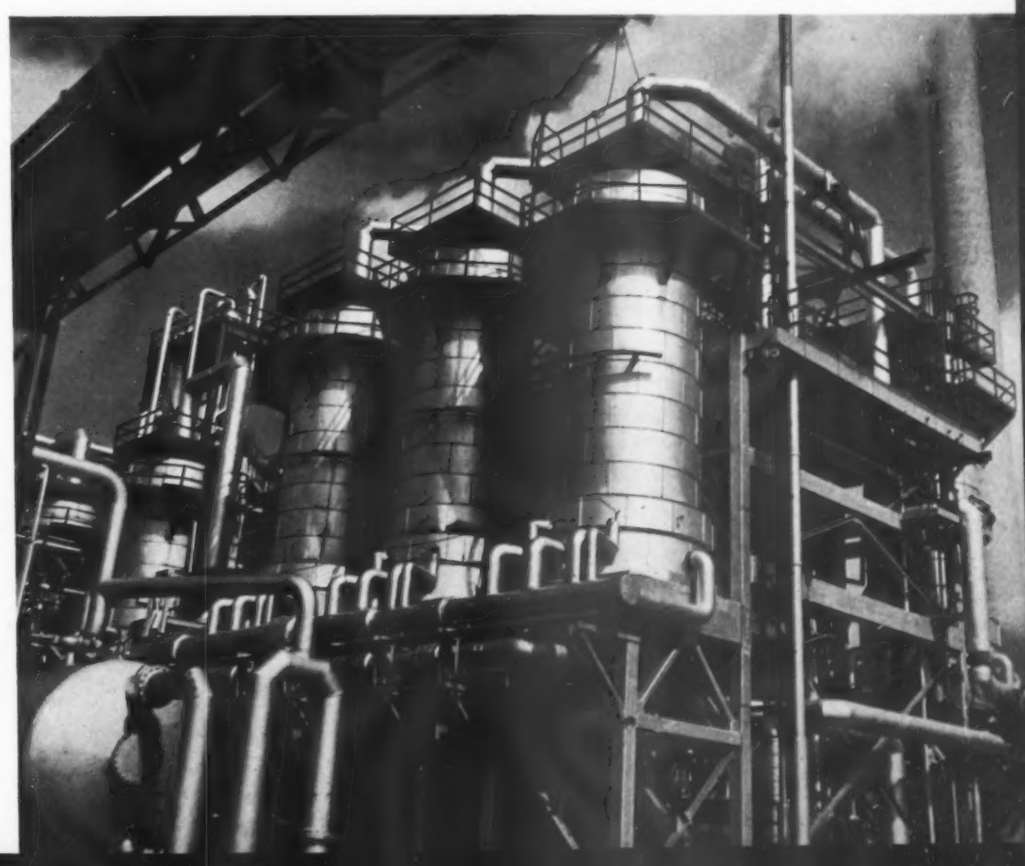
Up to this point the Houdry operations at Marcus Hook were still mostly devoted to the production of motor fuel, which at that time was being consumed by the public in record amounts. Commercial aviation was growing in importance and there was some demand for the higher grades of automotive fuel from the Army and Navy. Aviation gasoline has to be of a much higher quality (100 octane number) than the best ordinary motor gasoline (78 octane number). Most of the business of supplying aviation grades of gasoline naturally went to the catalytic cracking plants, because catalytically cracked gasoline is richer in octanes to begin with, and therefore requires a smaller proportion of high grade, specially manufactured blending agents.

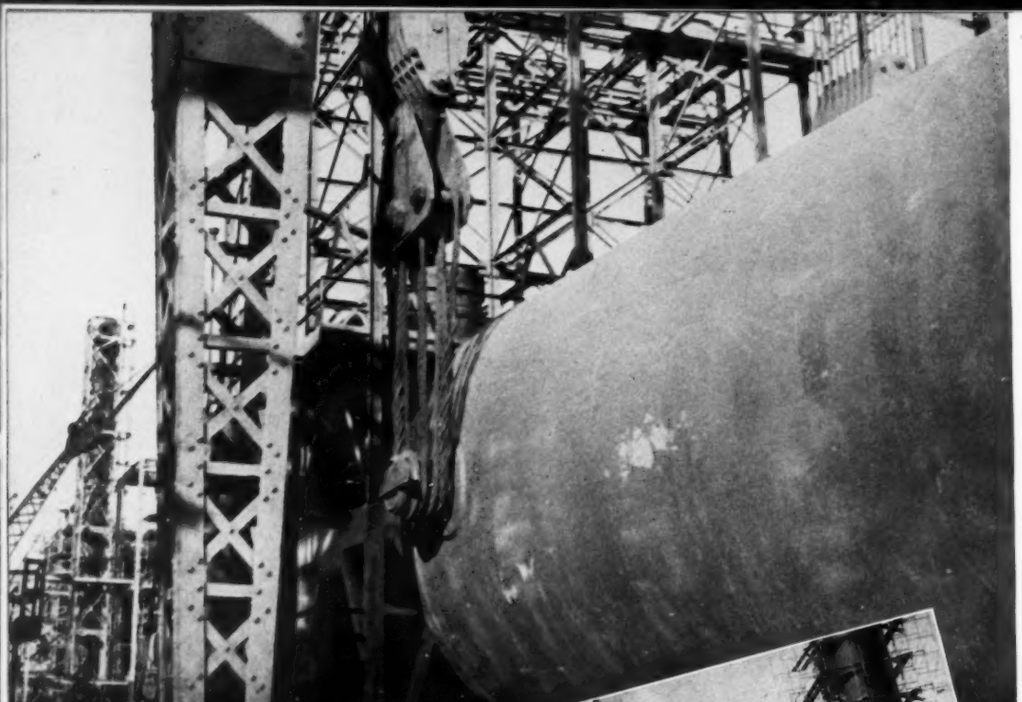
When hostilities broke out in 1939 and it became apparent that the United States was to become the arsenal of democracy, as well as to defend itself, and in particular would have to supply vast quantities of 100 octane gasoline for aerial warfare all over the world, it was a foregone conclusion that catalytic cracking facilities would have to be greatly expanded.

In view of this need, early in 1942 the Sun Oil Company approved a new program for the production of aviation gasoline at its Marcus Hook refineries and Toledo. Up to that time (as stated above) the Houdry system at Marcus Hook consisted of four units, two of which (plants 11-4 and 12-3) were working on reduced crudes, a unit attached to 12-3 for reforming Coast naphthas (later used as a treating unit), and another plant (10-3) which was working on gas oil for producing motor fuel.

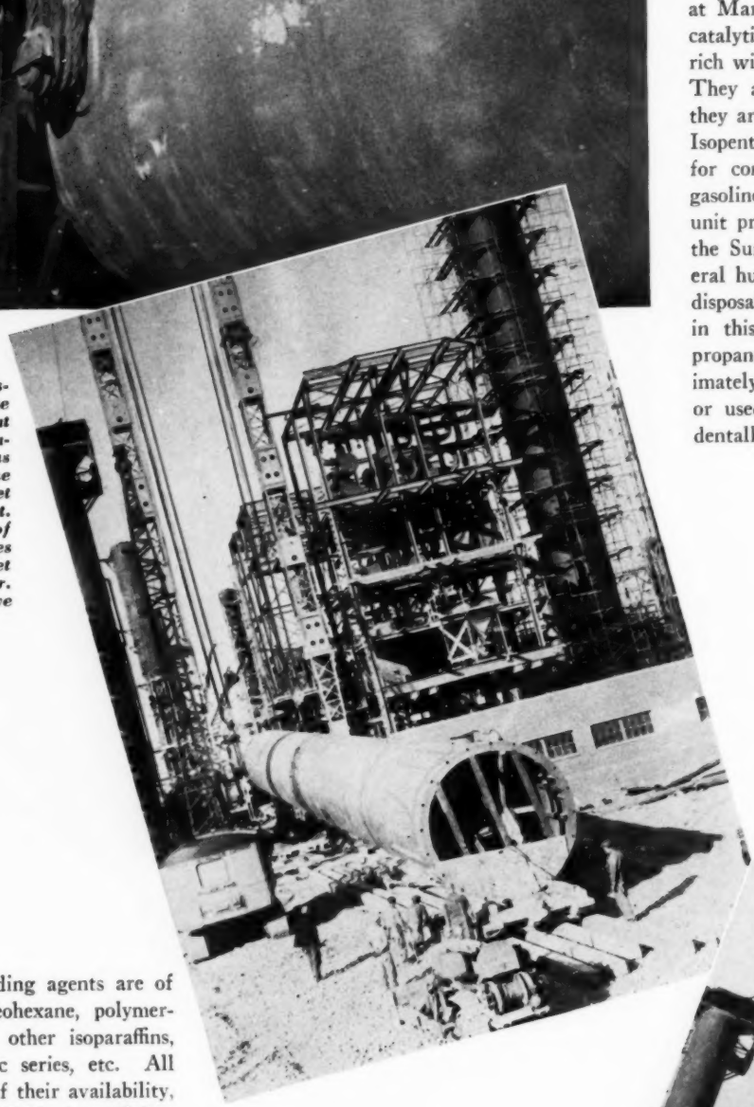
The central purpose of the new program at Marcus Hook was to make a nearly complete shift from the production of motor fuel to the production of the fighting grades. The shift away from ordinary gasoline was made necessary by the unprecedented demands of the military and the extreme scarcity of means for meeting that demand. The greater part of the American refineries were still operating by the thermal cracking process, the product of which is low in octanes and on the whole inadequate for use as a base stock for aviation gasoline. Catalytically cracked gasoline is much better for the purpose, but as it comes from the cracking cases it is not of aviation grade—it still does not have enough octane, which must be added in the form of

Houdry catalytic cracking plant at a Sun Oil Company refinery. This cracker has twelve catalyst cases and since U. S. entered the war has contributed more to the production of catalytic aviation base stock than any other in the world.

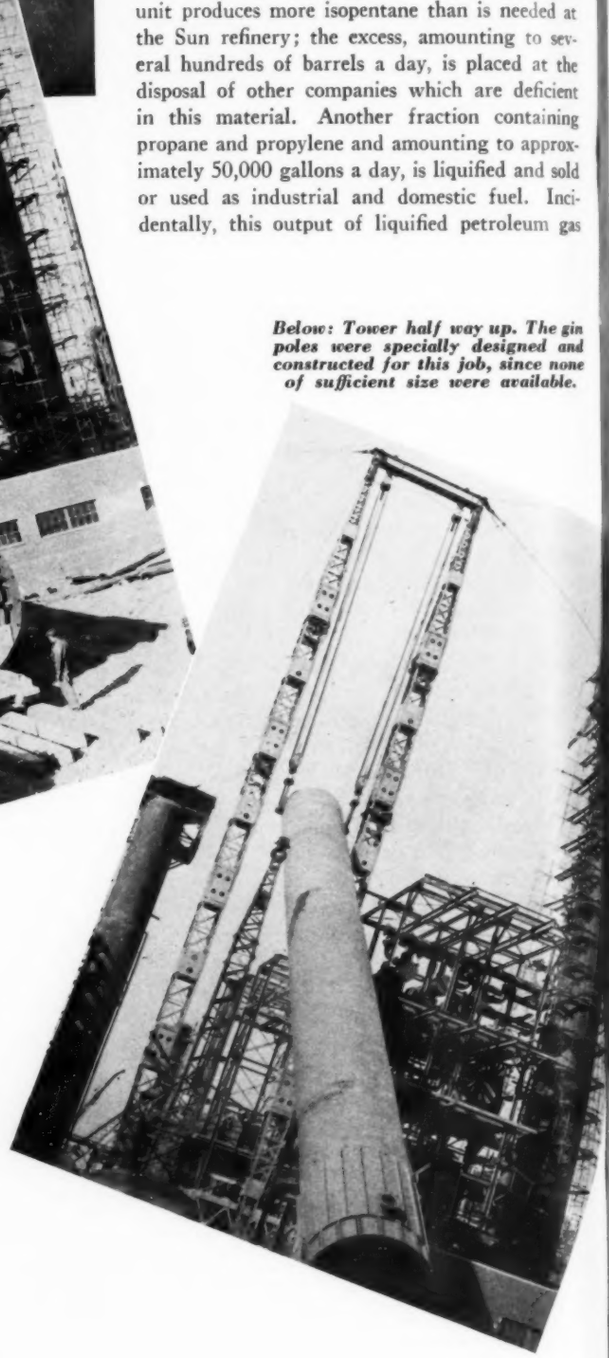




The following photographs illustrate the erection of the huge 310,000-pound deisobutanizer at Sun Oil Company's new aviation gasoline plant at Marcus Hook. This tower, one of the largest ever erected, is 150 feet high with a diameter of 11 feet. Photo above shows a closeup of the lifting attachment. Cables were attached to vapor outlet nozzles at the top of the tower. Arrangement of the blocks give tremendous leverage.



Above: Beginning of the lift, with the huge tower lying on the ground. The size of the tower is graphically indicated by the men working around the base and the mobile crane on the left.



Below: Tower half way up. The gin poles were specially designed and constructed for this job, since none of sufficient size were available.

blending agents. These blending agents are of different natures, such as neohexane, polymerized olefins, isopentane, and other isoparaffins, hydrocarbons of the aromatic series, etc. All these are used to the extent of their availability, but they were either not available in sufficient quantity, or the cost of producing them was relatively great. At the present time (overlooking other developments that have not fully materialized) the most available blending agent is the product of an alkylation process whereby an isoparaffin (isobutane, isopentane) is combined with an olefin (propylene, butylene, pentylene, etc.). The product is generally called "alkylate." The most favored combination is isobutane with butylene, as this directly gives a high octane blending agent. With a sufficiency of high grade base stock plus a few cubic centimeters of tetrethyl lead, a 100 octane aviation gasoline is readily compounded.

A self-contained plant for the production of finished 100 octane aviation gasoline therefore requires its own supply of alkylate. To provide this supply and to streamline the general operation, Sun's new aviation gasoline program included the erection of a fifth unit, known as plant 15, which has just come into operation. This is a combination plant, composed of three parts. One of these is called the "'gas plant," to which is brought all the refinery gases and unstabilized gasoline from other Houdry units at Marcus Hook, particularly the giant 12-case catalytic cracking 10-3 unit. These gases are rich with the stuff from which alkylate is made. They are compressed and fractionated so that they are suitable as feed to the alkylation plant. Isopentane, which is a valuable blending agent for conferring necessary volatility on aviation gasoline, is also segregated for that purpose. This unit produces more isopentane than is needed at the Sun refinery; the excess, amounting to several hundreds of barrels a day, is placed at the disposal of other companies which are deficient in this material. Another fraction containing propane and propylene and amounting to approximately 50,000 gallons a day, is liquified and sold or used as industrial and domestic fuel. Incidentally, this output of liquified petroleum gas

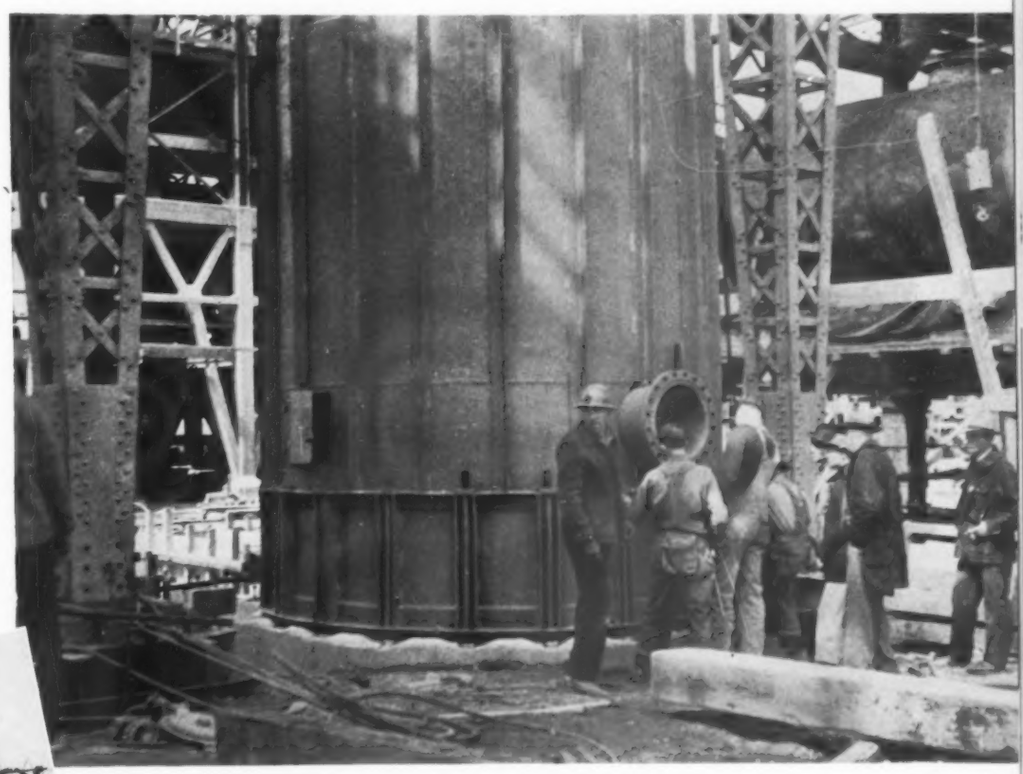
is an appreciable contribution to the stocks of this material on the severely rationed Atlanic Coast and by that much takes a burden off transportation from the Mid-Continent area.

The alkylation unit at plant 15 is designed to operate with hydrofluoric acid (HF) at the catalyst for effecting the union of the hydrocarbons in the mixture of isobutane and butylenes from the gas plant. The product consists of a mixed aviation alkylate that has an octane number of about 93. This plant for alkylation by the HF process, which in many respects is considered by some refinery technologists as an advance over the classic sulphuric acid process heretofore used for producing alkylate, is the second HF plant to go into operation in this country, and it is twice as large as the first one. The six contactors of this unit will circulate a gaseous mixture of hydrocarbon vapors and hydro-fluoric acid at a rate of 300,000 gallons a minute. The reaction generates a large amount of heat; to absorb this heat requires the circulation of cooling water at a rate of 16,800 gallons a minute. One dominant feature of this alkylation plant are two 150-foot fractionating towers, so tall that their erection is regarded as a noteworthy engineering feat. They are so large they require enormous quantities of condensing and cooling water, which is brought to plant 15 in a 3-foot main. A fraction containing isobutane, is segregated by these towers and returned to the new alkylation plant.

Already plans are being made to enlarge the capacity of this alkylation plant by 50 percent which can be done at moderate cost.

The third section of plant 15 is a new 6-case Houdry catalytic unit which is to be used for treating the one-pass aviation gasoline base stock purchased by other Houdry units at the Marcus Hook refinery. To this treating unit will also come one-pass Houdry catalytic gasoline from Sun's Toledo refinery. The capacity of this new unit is about half that of the big plant 10-3, and it has been laid out with the idea of ultimately doubling its size. The new catalytic unit will considerably relieve the burden on plant 10-3, which owing to shortage of catalytic cracking capacity has had to treat its own one-pass product; that is, it has been used alternately as a cracking and as a treating unit; under the new set-up 10-3 will crack continuously.

This combination plant 15 is a huge affair. Besides the gas plant, the alkylation plant, and the treating unit, its auxiliary equipment includes a steam generating system, water supply systems, tankage, pump houses, water treating plant, electric power substation, sewage disposal plant, office, laboratories, and the necessary shops and storehouse facilities. The total cost of plants and equipment in this group was approximately $9,000,000. Much of this equipment is automatically operated and controlled, requiring a minimum of attendance. On the other hand, the intricate chemical phenomena of the various processes requires strict laboratory supervision, and the staff of trained chemists and laboratory personnel outnumbers the operating personnel of the unit. This might be taken as an illustration of the tendency of modern technology to use more brains and less brawn.



Below: The tower hangs in a vertical position between the gin poles, just before the base is lowered on the foundation. On the right is a twin deisobutanizer tower.

Above: Anchor bolts being installed as the tower hangs a few inches from its foundation.

With the completion of plant 15, Sun's Marcus Hook refinery is a streamlined installation for the production of 100 octane number aviation gasoline. There is now a continuous flow of product from one-pass catalytic cracking units to second-pass catalytic treating units which meets a flow of blending agents produced on the spot and finally issues as an unsurpassed fighting aviation fuel.

While the huge installations at Marcus Hook are plainly visible to passers-by the nature of

the processes that go on in them are hidden from all but a very few. The various units are but mechanical instruments for affecting reactions which Houdry and Sun research chemists have long been developing and are still perfecting. The catalyst by which these reactions are affected is the real mainspring of the whole works. By comparison with the Houdry catalyst of 1943, the Houdry catalyst of 1937 was a crude one. It was made by treating a natural clay; though better than anything previously developed its efficiency was limited. Efficiency in this connection means, first, ability to transform a reduced crude or a heavy naphtha into a product containing a higher proportion of lighter hydrocarbons boiling within the gasoline range; and, secondly, to include among these lighter hydrocarbons a larger proportion of those light hydrocarbons that have the best anti-knock or octane ratings. The production of better and better catalysts for producing the fighter grade of aviation gasoline thus pursues the twin objectives of quantity and quality.

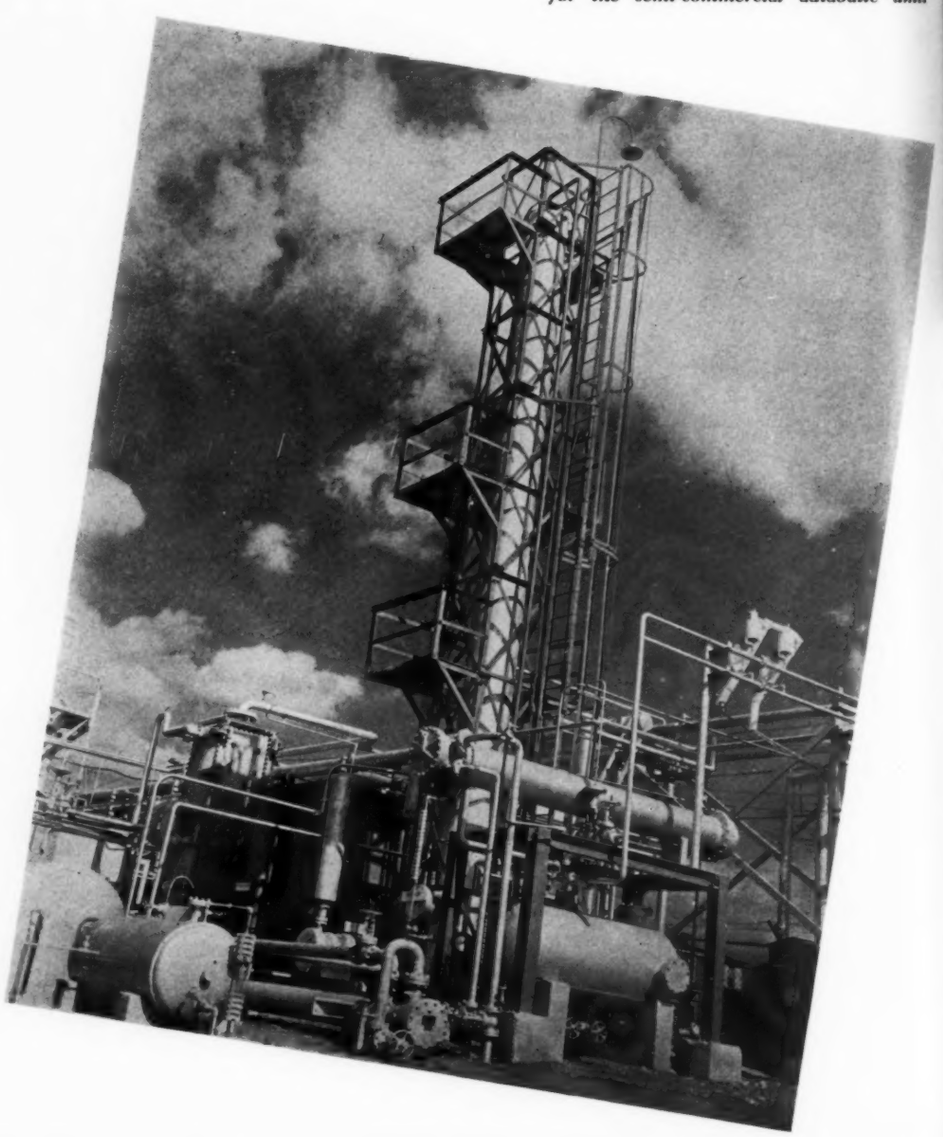
The first step in Houdry catalyst improvement was abandonment of the use of natural clays in favor of synthetic catalysts produced from chemical substances of definite characters so that the same finished product may be accurately reproduced. The first synthetic Houdry catalyst was a great improvement over the old natural one. After 1939 the need for better cracking and treating catalysts, particularly catalysts that produce more octanes, became especially manifest because of the demand for fighting gasoline that is better than the conventional "lean" 100 octane number gasoline. The original Houdry synthetic number basolie. The original Houdry synthetic catalysts have themselves been displaced by better ones, with still better ones in sight.

However, improvement in the performance of Houdry operations at Marcus Hook has not been solely due to the replacement of good catalysts by better catalysts. The efficiency of a catalyst depends not only on its nature but also on the manner of using it, and the best way of using a cracking or a treating catalyst has to be found out by experience. The method of operating a Houdry cracking unit that has been standard practice up to the present is to use molten salt as a means of controlling the temperature during the cracking portion of the cycle, and to keep down the heat developed during the regenerating operation. It is now possible to modify this practice so as to produce a new grade of super-aviation fuel. The new method is called the Houdry "adiabatic process," which has passed a thorough tryout on a large pilot plant designed and built by Sun engineers. Full details of the process are naturally withheld for the present, but this much can be said: Instead of using molten salt for removing the excess of heat resulting from burning off the coke in the regenerating operation, means are provided for storing a part of this heat within the catalyst case for use in the succeeding cracking operation. The pilot plant in which the success of the adiabatic process has been demonstrated has a capacity for 600 gallons per hour, and the operation is carried out at present in four stages. First, the naphtha charging stock is passed in vapor form through the catalyst bed under cracking conditions: the product is debutanized in a fractionating tower and the raw aviation gasoline stock is vaporized and again sent through the catalyst bed under treating conditions of pressure, temperature and feed rate; another passage through the debutanizing tower yields an aviation fuel of superlative quality. In a full-sized adiabatic plant the apparatus would be installed and connected so that these four operations may be reduced to two: a two-cracking pass, with one fractionating tower in the middle and another at the end. The existing pilot plant requires six operators per shift, the same number as will be needed for a full commercial plant. In addition, a force of about 25 men are required in the laboratory to test and analyze the products—another illustration of the preponderance of skilled personnel in the newer arts of petroleum refining.

The quality of the aviation fuel obtained in the Houdry adiabatic process has been described as so good that no existing automotive engine can fully utilize its power. In this connection attention may be called to the fact that so far as the higher grades of aviation fuel are concerned the octane scale of anti-knock and power ratings is no longer adequate. Not very long ago it was thought that no gasoline could have an octane number higher than 100, where the conventional octane scale comes to an end. But military aviation gasoline much more powerful than ordinary 100 octane number gasoline has for some time been in quantity production at various refineries: the adiabatic process is merely another means to that end.

In fact, another means to that end has been uncovered by Sun's research department, which has developed a process known as C.T.C. (catalytic-thermal-catalytic) a three-pass system in which a way has been found to combine the best features of catalytic and thermal cracking. The result is an aviation fuel that stands high on the new super-100-octane scale of power rating. Details of this process will not be revealed until after the war, and perhaps by that time the automotive engine builders will have produced engines that can fully utilize the capabilities of the new fuels.

A close-up view of the fractionating tower for the semi-commercial adiabatic unit.



NEW BEAD CATALYST

In the upper left-hand corner of this photo are pellets of natural clay catalyst. At the right are the synthetic clay pellets, and in the foreground are the TCC beads.

a product of team work in research

Result of Extended Laboratory Experimentation Is a New and Powerful Agent for the Production of High Octane Fuel—Plant for Bead Production Now Under Construction.

ONE of the great milestones in the progress of the petroleum industry was the development of the thermal cracking process. Coming along at the time of World War I it enabled refiners to obtain a much greater amount of gasoline from each barrel of crude than had been possible under straight distillation. Thereby it was made possible to meet the swiftly mounting requirements of the automotive age and to supply increasing quantities of motor fuel at steadily lowering costs.

Of similar importance in its relation to World War II has been the introduction of catalytic cracking without which it would have been impossible to provide the enormous quantities of high grade aviation fuel, butane, butadiene and aromatic hydrocarbons demanded by a war waged largely in the air and dependent upon highly specialized products. Catalytic cracking has been the subject of study for many years and had reached the stage of commercial application before the outbreak of the present war. A wide range of materials had been tried out and found to possess catalytic qualities but some of these were rendered unavailable by their cost and others were rejected for other practical reasons. The war itself however has greatly stimulated the search, particularly in the field of synthetic catalysts, for new, cheap and effective agents to increase the recovery of products in the higher range from those of lesser usefulness.

Because of the recognized importance of catalytic cracking in the war program and the practical certainty that it will be utilized on a great scale following the war to supply high powered fuel to motors of advanced design keen interest was aroused by the announcement early in the current year by the Socony-Vacuum Company that its research organization had developed a new form of synthetic catalyst that could be readily introduced into existing catalytic cracking plants and that possessed special attributes of high efficiency. Because of its form—that of

tiny spherical beads—it was called the bead catalyst. Its importance has been recognized by the recent issuance of governmental authorization of a special plant now being erected by The Lummus Company to manufacture the beads in quantity. Hitherto they have been produced only in the pilot plant operated by the company at one of its eastern refineries. Exact results in the production of aviation gasoline by use of the bead catalyst are withheld from publication for the present but it is permissable to say that they show a marked increase in engine power. In the case of regular motor gasoline it is stated that it is possible to produce 10-pound Reid vapor pressure fuel over the catalyst which shows a research octane number of 95-100 with one to three cc's of lead.

Socony-Vacuum has been closely identified with the progress of catalytic cracking for the past fifteen years. Together with Sun Oil Company it backed the experimental work of Eugene Houdry which resulted in the establishment of the Houdry process in the late thirties* and it operates a larger number of Houdry plants than any other one company. Subsequently it developed in its laboratories the TCC (Thermofor Catalytic Cracking) process which is being employed in some thirty plants built or building as part of the nation's war program. In taking up the search for an improved form of catalyst the members of their research organization were following along a trail which they themselves had helped to blaze. The story of this undertaking as related in the over-modest words of one of the men most closely connected with the investigation is set forth as follows:

"Numerous laboratories have worked intensively to produce synthetic catalysts having improved performance with respect to yields, quality of gasoline and other products, freedom from coke deposition, long life, and good ruggedness, all of which are obviously desirable characteristics. In the Thermofor catalytic cracking process (TCC process) specially treated natural clays were originally adopted as a catalyst because they were relatively cheap, costing only three to five cents a pound, and were available in the necessary large quantities required to carry out commercial operations on a large scale. Clays have reasonably good catalytic characteristics and when properly prepared are sufficiently rugged to give fairly low attrition losses in TCC units. On the other hand, conventional synthetic catalysts are comparatively expensive and in their regular forms, as pellets, pills, lumps or granules, are not sufficiently rugged to give economical attrition rates in TCC units. Thus in the early stages of TCC development the use of synthetic catalysts was not considered as commercially practicable. However, our engineers and chemists recognized that there were many applications where synthetic catalysts would give better performance and extra flexibility in the TCC process. For this reason, a research and development program was set up with the following objective: 'To produce synthetic catalysts capable of giving outstanding performance in catalytic cracking operations and of sufficient ruggedness to withstand attrition under TCC processing conditions.'

Dr. J. B. Rather of the Socony Vacuum Oil Company, one of the country's distinguished petroleum scienists.

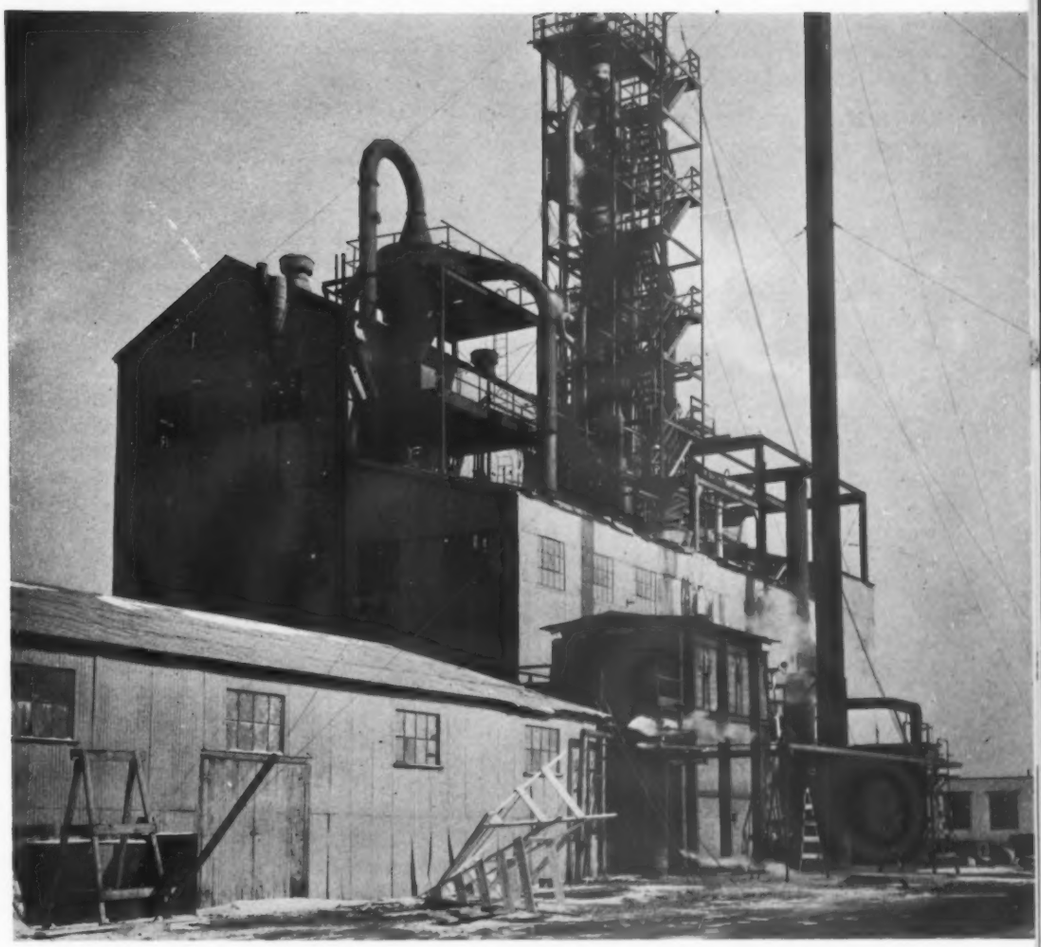
"With this goal in mind the engineers and chemists went to work. Hundreds of catalysts were prepared; compositions were varied; conditions were changed; new and untried techniques were explored, and as the experimental work progressed a number of promising methods were discovered. After the program was well advanced a brilliant young chemist finally succeeded in preparing a few cubic centimeters of small glass-like catalyst beads and this accomplishment represented the birth of the TCC bead catalyst.

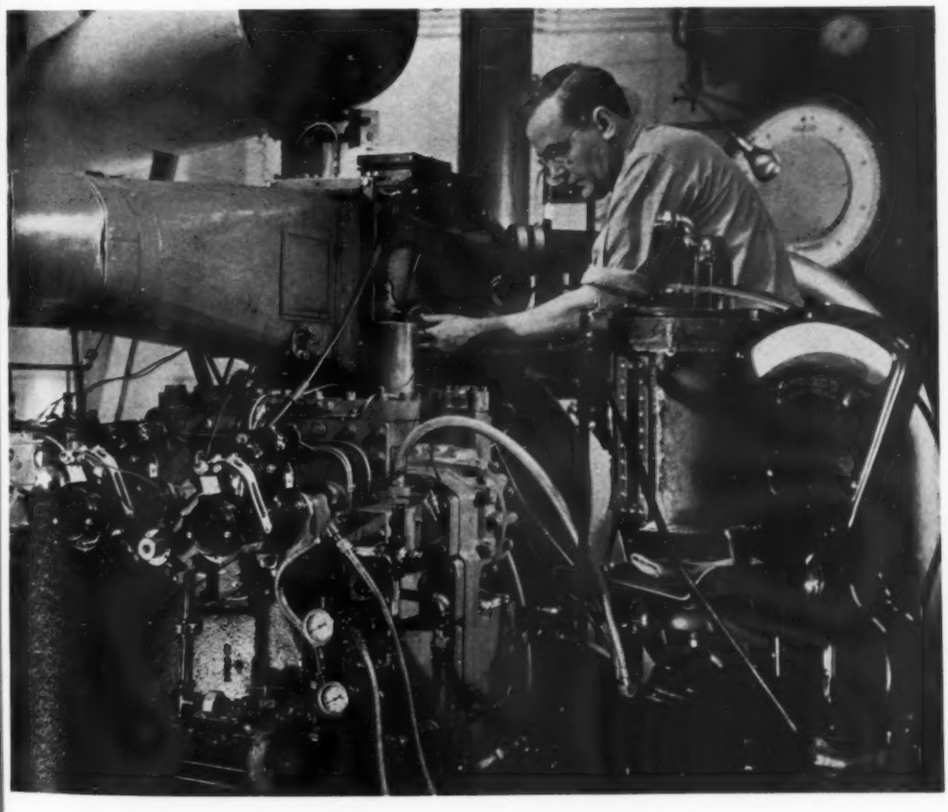
"At first it seemed unbelievable that these glass-like bead particles would be good cracking catalysts. It required a great deal more painstaking work to prepare the additional few ounces of beads required for the initial catalytic appraisal which proved that the beads not only possessed exceptionally good catalytic activity but that they were also extremely hard and rugged. With these facts established the next step was to determine the feasibility of manufacturing them commercially. This development phase of the work was conducted by chemical engineers, many of whom had contributed previously to the development of the TCC process. This work was carried out intensively.

"The bead catalyst manufacturing process combines many steps and each step involves the control of several important sensitive variables. Numerous pilot plants were built and operated to study each variable and in the end these steps were combined into a single continuous pilot plant operation producing finished TCC beads as the end product. The beads produced from pilot plant operations were then thoroughly evaluated in several pilot cracking units to establish their expected commercial performance. The results were highly gratifying and led to

* For first authoritative account see WORLD PETROLEUM, October, 1938.

T. P. Simpson of General Laboratories' Research and Development Division shown explaining the process to Socony-Vacuum department heads.





Above: TCC pilot plant. The high efficiency of the new TCC beads has been demonstrated with the aid of this equipment.

Left: With elaborate laboratory equipment, the performance of the gasoline made over TCC beads is tested in the Research and Development Division of General Laboratories.

the following conclusions, concerning the TCC synthetic bead catalyst:

"(1) Being spherical the beads are considered as having the ideal form for use in the TCC process. Spherical particles are considered as having a number of technical advantages. They give a high percentage of fillage in a given space; they are free from sharp edges or corners thus reducing tendencies to chip and scrape; they flow more uniformly than irregular shaped bodies; they form void passages of uniform character and present a minimum of external surface for wear.

"(2) Beads have remarkable strength and are very resistant to attrition under TCC operating conditions.

"(3) Beads give exceptionally high yields of motor and aviation gasoline base stocks of outstanding quality. They are catalytically stable and will have long life.

"(4) Beads can be manufactured in large quantities at reasonable cost in a plant requiring only a small proportion of critical materials. A single plant now under construction will produce about two and a half million beads per day—or at the rate of about 30,000 beads per second."

Although not mentioned in the above statement the development of the bead catalyst is a good example of the sort of team work that produces most of the noteworthy advances in applied petroleum technology. The research was carried on in one of the four laboratories which the company maintains at an expense of nearly three and a half million dollars a year. Their activities are conducted under the general direction of Dr. J. B. Rather, one of the country's distinguished petroleum scientists. The actual inventor of the catalyst is Dr. Milton M. Marisic who studied and tested thousands of combinations before arriving at a final successful result. Although still a young man Dr. Marisic has specialized in the field of physical chemistry for a number of years with particular attention to the study of catalytic action.

Another petroleum engineer, Theodore W. Nelson, a member of the research group, took the beads produced by Dr. Marisic in his laboratory and directed a long study of their action upon a wide variety of cracking stocks. L. P. Evans, a development engineer, conducted the experimentation in the actual production of catalytically cracked gasoline in a TCC pilot unit. John W. Payne, heading a group of chemical engineers, had the responsibility of working out the equipment and the processing methods needed for the manufacture of the catalyst in a small pilot plant erected at the research station. Ernest Utterbach, mechanical engineer of the process engineering and design division of the Company's manufacturing department, aided by another group, took the findings of the experimenters who had carried the work through these earlier stages and developed the equipment for producing the beads on a commercial scale. T. P. Simpson was in charge of the development both of the bead catalyst and the TCC process. Thus the combined efforts of a great number of specialists entered into the ultimate result of broadening the field of service of the petroleum industry.

While the name applied to the bead catalyst conveys a good general impression of its appearance it is more specifically described as consisting of small translucent spherical particles each about one-seventh of an inch in diameter. An individual bead will carry a load of about 200 pounds before crushing. A mass of beads packed in a column will sustain a weight equivalent to 3,000 pounds per square inch without breakage. In a laboratory test where the particles were carried in an air stream flowing at the rate of 104 feet per second against a solid steel plate they showed no breakage and only three percent wear after passing through 90,000 cycles of this treatment. From these and other tests it is estimated that the catalyst will prove serviceable for at least a year under commercial operation. In point of toughness, durability and freedom from serious loss by abrasion little more could be asked from it.

(*Continued on page* 81, *third column*)

Below, left to right: Dr. Milton Marisic, Theodore W. Nelson, L. P. Evans, John Payne and Ernest Utterbach.

MASS SPECTROMETER

AIDS ANALYSIS OF GASES

ELECTRONICS is relatively a new word in the vocabulary of the non-technical man but developments in this field, particularly in their relation to war activities have been the subject of much discussion in the past few months and have resulted in some surprising accomplishments. One of these of particular interest to oil men since it was developed by petroleum physicists for the petroleum industry is the mass spectrometer.

This amazing instrument—only one has been built thus far—occupies a closely guarded laboratory in a Philadelphia refinery. It is designed to perform an important service in connection with the production of petroleum materials for war use and came into existence through the combined efforts of the research organization of The Atlantic Refining Company at Philadelphia, and of the Consolidated Engineering Corporation at Pasadena, California, working together though separated by the breadth of the continent.

Experts declare this development makes possible a marked improvement in the analysis of gases which are used in making high octane aviation gasoline and synthetic rubber stocks, and opens the door to unlimited research in these fields. In addition to improving present production methods, it is expected that the mass spectrometer may pave the way for the development of entirely new gasolines. The courage of both companies was put to the test in pioneering this extraordinary instrument through its transition from the experimental stage to industrial performance. The Consolidated Engineering Corporation, of which Herbert Hoover, Jr., is president, had the vision to recognize the dormant possibilities of a mass spectrometer as well as the skill and patience to solve a multitude of problems in design, manufacture and precision operation. Dr. Harold Washburn, director of research for Consolidated, deserves major credit for the unique features of this instrument and for his skillful management of the necessary staff of electronic and mathematical experts.

It was while investigating the possibilities of soil analysis in discovering oil deposits, that the Research Department of The Atlantic Refining Company, under the direction of Dr. T. G. Delbridge, one of the country's alert scientific organizations, first became associated with the Consolidated Engineering Corporation. As a consequence of their extensive activity in the war effort, Atlantic research scientists promptly saw the many practical applications made possible by Consolidated Engineering Corporation's development, and persuaded the latter company to build a mass spectrometer for use in aviation gasoline and other strategic programs.

Dr. O. L. Roberts, of The Atlantic Refining Company's Research Department, is in charge of the operation.

"We are confident that the mass spectrometer will greatly extend our ability to make better gasoline, better synthetic rubber and other products, not for war only but for peace as well," said Dr. Roberts. "Today analysis of petroleum gas is a real bottleneck, demanding more analysts and equipment than the industry has available. The Consolidated mass spectrometer gives the power and vision to do what heretofore was deemed impossible."

Dr. Roberts enumerated the advantages of the mass spectrometer technique over the old distillation method of analysis as follows:

1. The use of the mass spectrometer permits analysis of some gases that cannot be separated by distillation procedure. Such extension of the ability to determine hydrocarbons in gasoline may lead to the development of better, or even new gasolines.

2. The new method is eight times as rapid as the old. This results in closer control of plant operations, as rapid analysis of samples permits more frequent testing and checking plant equipment.

3. In the old method, the care used by the analyst was an important factor, and because of the human element, the results often varied greatly. The mass spectrometer eliminates this variable.

4. To make tests and check tests, past procedure required one cubic foot of gas, three hundred-thousand times as much as is needed by the mass spectrometer.

Because of its importance to war production the instrument is now being operated under a policy which limits disclosure of its results to those engaged in the national effort to manufacture greatly increased quantities of high grade aviation fuels, and details of construction and operation are kept secret. Weighing slightly more than two tons, and small enough to fit into an ordinary-sized kitchen, the mass spectrometer looks like a high-powered radio transmitter.

Dr. O. L. Roberts (standing) and Dr. T. G. Delbridge (seated) of the Research Department of the Atlantic Refining Company, shown operating the mass spectrometer.

THE FLUID CATALYTIC CRACKING PROCESS

THERE are now currently three main types of catalytic oil cracking processes in large scale operation for the production of the stupendous quantities of high grade aviation gasoline that are being consumed by the Allied forces. These processes go under the names of Houdry process, Thermofor process and Fluid Catalytic Cracking process respectively. All these processes are similar, in that they expose petroleum vapors at elevated temperatures to contact with a solid, mineral catalyst, whereby the vaporized oil is transformed into materials usable in the manufacture of aviation gasoline, synthetic rubbers, and toluene, along with certain other substances of importance in the war program.

The question of whether one of these catalytic cracking processes is better than the others, and if so why, will not be settled until after the war, when the petroleum industry again gets back to a competitive basis on which only the most efficient and inexpensive of them will survive. In the present emergency, the armed forces need every drop of aviation fuel that can be produced by any and all processes that are at all workable, and to meet this need new plants of all three types have been designed and built.

While agreeing in principle and in the general results of their operation the three catalytic processes differ in practical details. The Houdry process employs a synthetic catalyst in granular form, which is enclosed as a fixed or motionless bed in the catalyst chamber, where it is perfectly revivified by burning off the carbon that has been deposited on the granules during a cracking operation. The Thermofor process also employs a synthetic catalyst in granular form, but instead of maintaining the catalyst in a fixed bed the granules are allowed to flow downward against an ascending stream of hot petroleum vapors. On reaching the bottom of the reaction chamber the granules are revivified by taking them to the top of another chamber, down which they travel against a current of air which burns off the carbon; they are then returned to the reaction chamber to repeat the process.

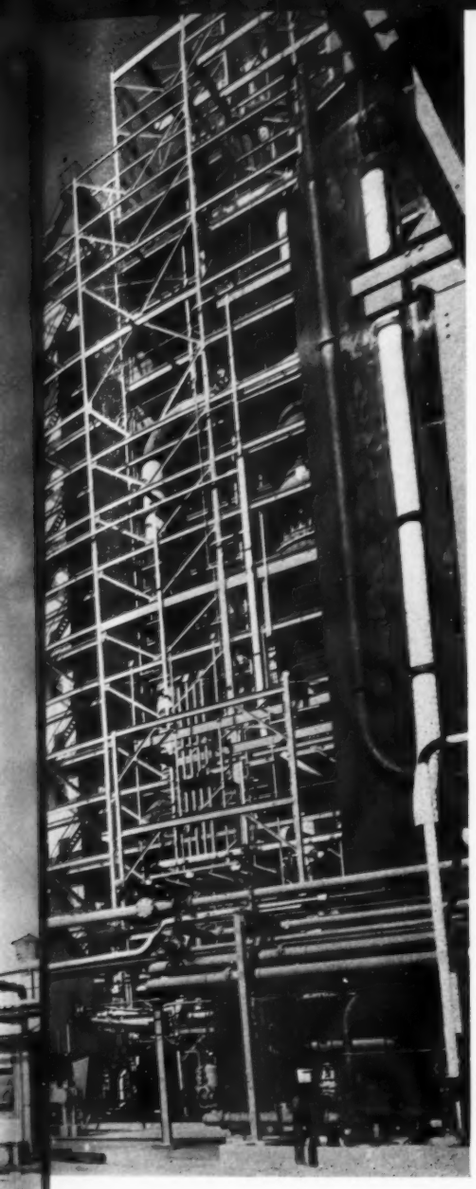
The Fluid Catalytic Cracking process also uses the principle of keeing the catalyst in motion, but in this process the catalyst, instead of being in a granular form, is ground to a fine dust. For the manipulation of this dust it has been necessary to design a unique assembly of apparatus. The general course of these manipulations may be followed with the aid of the accompanying diagram.

In the above photo at left are two new fluid catalytic cracking units which supply a tremendous stream of war materials such as 100-octane aviation gasoline and raw materials for synthetic rubber. The fluid cat cracker at the right has been in production for a year.

Oil enters at point (A) and is vaporized in a furnace (B). The oil vapor then proceeds to the reacting chamber, picking up en route the finely powdered catalyst at the mixing point (C). Beyond this point the catalyst, aerated by the oil vapors, flows in a manner very similar to liquid flow. Entering the reactor (D), velocity is lost, increasing the density of the catalyst-gas mixture at that point, and thus increasing both the time and intimacy of contact of the catalyst with the reacting gases. The density of the catalyst gas mixture in the reactor chamber varies, but is in the order of magnitude of 15 pounds per cubic foot. Vapors leave the reactor at the top, carrying with them the catalyst powder, which is then separated in a series of cyclone separators at (E). The cracked vapors, now free from the powdered catalyst, pass overhead into conventional fractionating equipment (F) which segregates the products into gases, gasoline, heating oils, etc.

The separated catalyst is collected in a so-called "spent catalyst hopper" (G) where it attains a substantially higher bulk density than in the reaction chamber. The mass of powdered catalyst, however, is maintained in a "fluidized" condition by the admission into the catalyst hopper and the standpipe of a small amount of steam or other gas. It is a remarkable fact that a fine powder can be maintained in an extraordinary fluid state in this manner and behaves in fact as a liquid.

This "fluid catalyst" flows downward from the spent catalyst hopper through a standpipe adequate in height to develop the necessary static pressure at its lower end, where a valve controls its admission into an air stream from a blower (I). This air stream picks up the spent catalyst and literally blows it over into a regenerator chamber (J), where, again, gas velocity is reduced to produce a denser mixture. The regenerating chamber is maintained at relatively high temperatures, and carbon deposit on the catalyst is burned off. Catalyst and the combustion gases leave through the overhead system, passing



through the regenerator cyclones (K) in which the regenerated catalyst is removed from the exit flue gases. Traces of catalyst remaining in the exit flue gases are later removed and returned to the system by means of the electrostatic precipitator (L). The regenerated catalyst is collected in the regenerated catalyst hopper (M) whence it is delivered by the regenerated catalyst standpipe (N) to the mixing point (C) which completes the catalyst cycle.

Control of temperature in the regenerator is necessary and for this purpose additional regenerator catalyst is circulated through a separate standpipe (P) from the regenerated catalyst hopper, and through a bank of heat exchangers (Q) by which heat is removed from the flowing catalyst. Temperature control is accomplished, therefore, by controlling the rate of recirculation of catalyst through these heat exchangers. Heat from these exchangers may be used for various purposes, including preheating the oil feed to the vaporizing furnace.

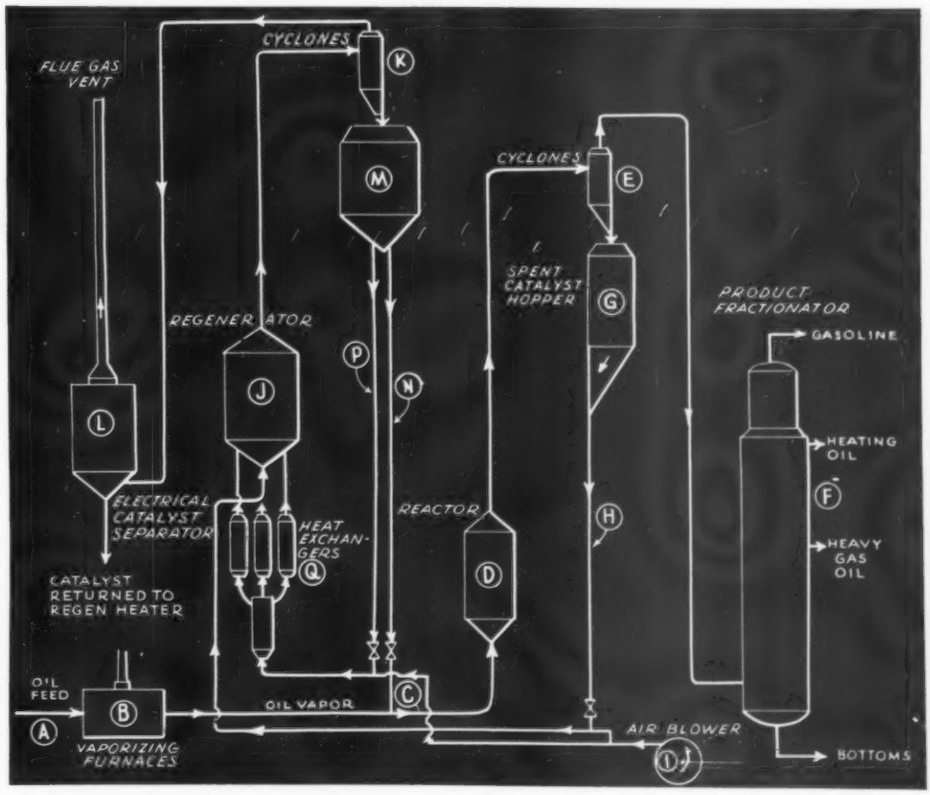
It is of particular interest that no mechanical devices of any nature are used in circulation of the catalyst throughout its entire circuit.

Energy requirements are supplied by the pressure in the oil feed and by the pressure of air from the air blowers. The regenerated catalyst standpipe (P) is of sufficient height to develop the static head at the lower outlet that is necessary for introducing catalyst into the entering vapor system. Despite the simplicity of this operation, the quantity of catalyst which can be circulated is exceedingly high, measured literally in hundreds of tons per hour.

Aside from the mechanical simplicity in the fluid catalyst system, of importance is the fact that the temperatures maintained in both the reactor and in the regenerator are exceptionally uniform. Measurments have indicated a maximum temperature variation from point to point within the reactor, or in the regeneration, of about five degrees F., which is probably within the actual limit of measuring such temperatures. Moreover, this indicates an extremely high degree of turbulene within the reaction vessels, giving a highly uniform catalyst activity throughout the reaction and regeneration vessels.

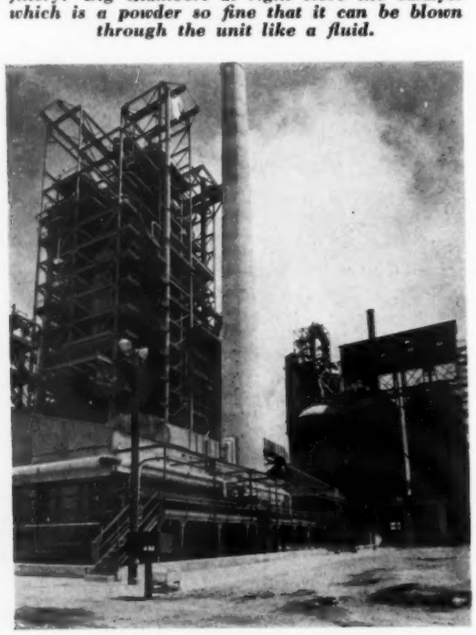
The Fluid Catalytic Cracking process as outlined in the above description was developed in this country by the Standard Oil Company of New Jersey, which originally held the basic patents. This company has three such plants of its own now in operation, and has under construction five more, each costing around $6,000,000. Under the system of pooling all patents, processes, and "know how" that has been instituted for helping to win the war, other oil companies have been enabled to use the process, and according to latest information 26 other plants to work by fluid catalytic cracking are under construction or design, and there is likely to be many more unless the Axis collapses very soon.

Attached to every catalytic cracking plant that operates by either of the three processes there is a fractionating tower. These towers differ from the type that was common before the war, in that they have to perform a more exacting function. The cracked vapors that have been freed from the catalyst dust by the cyclones and the electric precipitators contains products that used to go into ordinary motor gasoline, but which the situation created by the war has invested with new and higher values. The pre-war motorist was well satisfied with a premium gasoline that might have an octane number of 80, due to the presence in it of an average mixture of hydrocarbons of high and low anti-knock values. But the supreme need of the moment is for aviation gasoline that has an octane number of 100, and even beyond 100. The components of the cracked vapors that have high anti-knock values, or which may be reworked to become fit components of fighting grade aviation gasoline, must now be sharply separated from components of inferior grade. Not only that, there is a need for petroleum products to which the prewar oil refiners hardly ever gave a thought, namely, the olefins that form the basis of the various kinds of synthetic rubber. To separate all these components the refiners have had to carry the art of superfractionation to new levels of efficiency, for which they need distilling columns of unprecedented heights, in some cases reaching 100 to 150 feet. In traveling up from the bottom to the top



of these tall towers the cracked petroleum vapor successively drops its components, or certain mixtures of components. The components of high gravity and high boiling points drop out first, until at the top there are left only incondensible gases from which other values may or may not be extracted. In a typical Fluid Catalytic Cracking plant, such as the Bayway plant of the Standard Oil Company of New Jersey, two grades of fuel oils are tapped from the lower section of the fractionating tower. The next fraction consists of all of those condensible hydrocarbons that have boiling points of 400° F. or lower. They include the saturated hydrocarbons ethane, propane, normal and isobutane, normal and isopentane; the olefin hydrocarbons, ethylene, propylene, normal and isobutylene, and various others which it is desirable to have as components of motor gasoline or aviation gasoline. To some extent one or more of these constituents may be taken directly from the tower, but for the completed separation the fraction boiling below 400° F. is redistilled in separate columns, arranged in series. The object is to "cut" the stream of these vapors into separate fractions, each containing hydrocarbons, the molecules of which contain the same number of carbon atoms, as C_3, C_4, C_5. In this fractionating process a mixture of C_3 and C_4 passes out at the top of the column into a depropanizer, where C_3 and C_4 are separated. The C_3 is proper feed for a plant which makes isopropyl alcohol, or it may be separately cracked on its own account to produce propylene, which is used in synthesizing blending agents for aviation gasoline. The C_4 cut, which is mixed with some C_5, contains normal butylene which is segregated for use in manufacturing either Buna-S rubber or alkylate; isobutylene, which is employed in making butyl rubber, and normal butane, which has various well known uses. Another fractionation step separates the C_4 from the C_5, which is mostly added to the aviation gasoline base stock.

Close-up view of the fluid catalytic cracking unit at the Standard Oil Company's Baton Rouge refinery. Big chambers at right store the catalyst which is a powder so fine that it can be blown through the unit like a fluid.



The above paragraph is a general outline of a process that is subject to a wide range of variation in the kind and quantity of the various constituents that enter the fractionating tower. These various constituents have their origin in the reactor of the Fluid Catalytic Cracking plant, where the cracking operation may be varied according to the kind of charging stock available at the moment, the kind of aviation gasoline product that is wanted, and also according to what auxiliary equipment may be at hand to offset secondary conversions.

According to information contained in a paper presented before the last meeting of the American Chemical Society by E. V. Murphree and C. L. Brown of the Standard Oil Development Company together with H. G. M. Fischer, E. J. Gohr and W. J. Sweeney of Esso Laboratories, a characteristic of the Fluid Catalytic Cracking process is a flexibility which allows operations to be carried out over a wide range of cracking and regeneration temperatures, as well as depth of cracking. The reaction temperatures can be varied both by means of heat applied to the oil in the furnaces and by the amount of hot catalyst circulated. Normally, the temperature in the reactor may range from 800° F. and 1000° F. The depth of cracking is governed by both the amount of catalyst in the reaction zone and by the ratio of catalyst to oil flow.

The pressure during the fluid catalyst operation, which also has an influence on the character of the cracked products, can be held at any desired point. In most of the cases in which gas oil is cracked by this process the pressure at the top of the reaction vessel is of the order of 10 pounds per square inch.

If the object were merely to produce ordinary motor gasoline, the stock would be contacted with the catalyst at a moderate temperature in a single-pass operation. In such an operation about 49 percent of the gas oil would be converted to a motor fuel with an octane number of over 90, and with some sacrifice of yield even higher octane numbers may be attained. But the prime object now is to produce war products including the highest quality of aviation gasoline, raw materials for synthetic rubber, and synthetic toluene. For obtaining these war products it was not necessary to make any basic revisions in basic equipment or design. The operation, however, was changed by using a catalyst of a different type, and by cracking more severely at a higher temperature. This treatment produces a more desirable product in the aviation base range, and an increased yield of the butane fractions required as raw materials for high quality blending agents and for synthetic rubber.

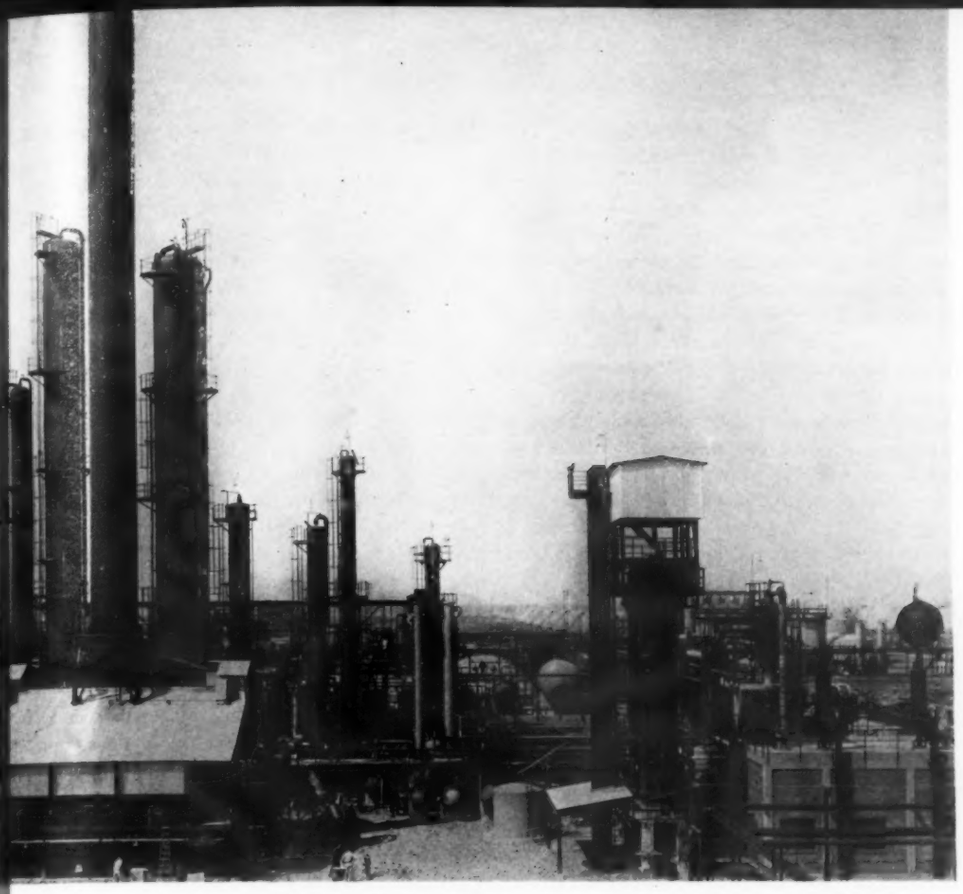
For instance, in a single-stage high temperature operation with gas oil and a suitable catalyst there is obtained a high yield of olefins and isobutane suitable for alkylation, and a gasoline containing fairly large amount of toluene, xylenes, and higher aromatics. The rate of conversion in this operation is about 65 percent. This gasoline, when it has been freed from olefins, is valuable as a blending agent with or without further treatment. On the other hand, the olefinic fraction may itself be turned into a good blending agent by hydrogenation. However, the use of the olefinic fractions depends on how the rival claims of the aviation gasoline and the synthetic rubber programs are adjusted. If one of these programs gets more, the other must get less.

The above relates to an operation in which the vaporized gas oil is passed only once through the catalyst reactor. Aviation gasoline of high quality may be produced by subjecting the cracked products obtained in the first pass to a further catalytic treatment, for which the original cracking unit (or a separate retreating unit) may be used. The quality of the product of the two-stage operation is raised to the order of roughly 97 octane number. This increase in quality is obtained partly through the saturation and elimination of the lower boiling olefins, and partly through the concentration of aromatics in the higher boiling fractions. This two-stage operation has particular merit where hydrogenation equipment is not available and where the refinery has only a limited supply of natural light blending agents.

Cracking operations with the same catalyst may also be carried out at relatively low temperatures in a single-stage operation to produce an aviation gasoline which, without further processing, may be used directly in aviation blends. The quality of this material when produced from commonly available paraffinic gas oils is inferior in certain aspects to that produced from operations at higher temperatures. On the other hand, certain naphthenic gas oils adapt themselves readily to these low-temperature cracking operations, and result in a product high in leaded octane number. A disadvantage of low-temperature cracking conditions is the low qualities of the olefins that are made available for the production of aviation alkylate.

Aside from the methods sketched above for utilizing the Fluid Catalytic Cracking process for the production of high quality aviation base, there are other methods that may be attractive to certain locations. The fluid cracking process is not solely a producer of aviation base but does also simultaneously produce raw material for alkylation.

Assuming that 100 bbl. of paraffinic heavy gas oil are fed to a fluid catalyst unit, it is possible to produce 78.4 bbl. of 100-octane fuel meeting present specifications. Extraneous quantities of isobutane are utilized in this integrated operation, due to the fact that the amount of isobutane produced in the catalytic unit is not sufficient to alkylate all the C_4 and C_5 olefins.



Alkylation and isomerization unit at a Midwestern plant of Cities Service Co.

ISOMERIZING,

A New Tool for Making Aviation Gasoline

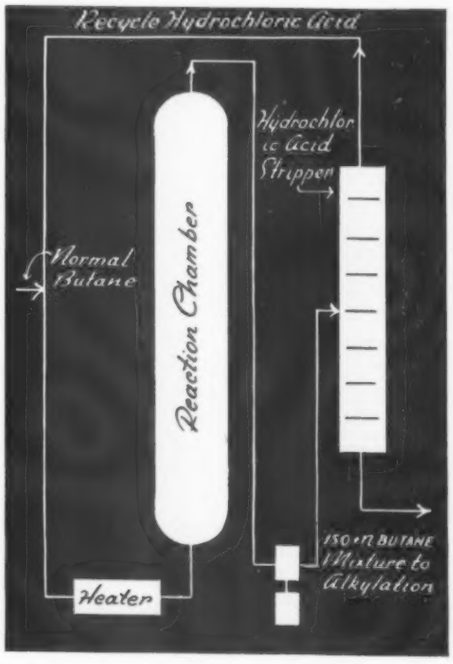
IT HAS been the custom of some writers to refer to the processes of cycloversion, isoversion, alkylation, cracking, reforming hydrogenation, polymerization isomerization, etc., as the refiner's "tools" with which a great diversity of hydrocarbons and their mixtures is transformed into products needed for civilian and military purposes.

While every one of these processes has an indefeasible place in refining technology, a special interest currently attaches to processes of isomerization as a means of building up the power of aviation grade gasoline. The base stock for airplane fuel must be of high octane number and possess the requisite physical properties. No natural petroleum product, and many of the ordinary intermediate products of petroleum refining, has either the required octane number or the required boiling range. It is the refiner's task to confer these properties on petroleum products that lack them, and in accomplishing this task more and more use is being made of processes that result in isomerization.

It is well understood among chemists that isomerization means changing the form of a molecule without changing the kind or the number of atoms in it; such transformations are often desirable because the chemical activity of a molecule depends greatly on how its constituent parts are put together. In the fabrication of a gasoline for bombers and fighter airplanes nearly everything depends on how the atoms are arranged in the hydrocarbon molecules. If these molecules are in the form of long chains of carbon atoms the gasoline will "knock" in the engine and deliver little power. Cut off the two ends of the long molecular chain and tie them back on the sides of the central section, and the resulting isomerized gasoline may be of superlative quality. By making the molecules shorter and rounder (branched) they are easier to burn in the engine and they deliver their power with much less waste of energy.

The petroleum refiner now has numerous methods of making long hydrocarbon molecules shorter and rounder. These methods differ in refinement of technique and precision of operation. The thermal cracking process, to which most of the annual flow of crude oil is still subjected, is in some degree an isomerization process, in that it breaks up long molecules or converts them into branched chains. The work accomplished in the thermal cracking stills is carried a step farther in the reformer units. In catalytic cracking and reforming the isomerization process is pushed to a much farther extent than in thermal cracking; this accounts for the superiority of catalytically cracked gasoline as an aviation base stock. At the present time there are no less than eight thermal or catalytic isomerization processes in commercial use; some of these are obsolescent and on the way out, and some are aimed at the production of special wartime products, such as isomeric hexanes. Although the isomerization of any long-chain hydrocarbon molecule will generally improve its octane rating, for aviation gasoline the refiner's interest is confined mostly to the shorter chains, the C_4, C_5, C_6, and C_7 paraffin hydrocarbons, or their mixtures. Of late it has become a practice to segregate fractions of distillate rich in these hydrocarbons and subject them to special thermal or catalytic treating processes which produce a high degree of isomerization, and give a mixed "isomate" that has a high blending value with aviation gasoline base stock. By one or other of these thermal or catalytic treating processes normal hexane (C_6) and even normal heptane (C_7), which of themselves have low ratings on the octane scale, may be transformed into isocompounds that rate near the top.

While the direct conversion of the C_6 and C_7 normal hydrocarbons or mixtures containing them into powerful aviation fuels now has considerable importance and holds large promise for the future. Chief reliance is at present placed on the shorter butane (C_4) and pentane (C_5) chains, especially the butanes. Normal butane and normal pentane of themselves have high octane ratings, but isobutane and isopentane rate still higher; the physical properties of these isohydrocarbons leave something to be desired, but a practical way has been found to get around this inconvenience. This way is to isomerize



normal straight-chain butane to isobutane, and then combine the isobutane with another hydrocarbon (in this case butylene, which is an olefin hydrocarbon) to form a larger molecule known as octane (which in practice is really isooctane). Although the molecule of isooctane is a fairly large one, it is highly branched (rounded) and therefore burns very satisfactorily in the engine. Its "octane" rating is 100, and it is the standard by which the anti-knock value of all gasoline fuels for civilian and military use is measured.

So far as the current great American aviation gasoline program is concerned, the center of interest in this connection is on the isomerization of normal butane to isobutane, for two reasons: first, that there is an abundant supply of normal butane and of butylene (which is formed in all petroleum cracking processes, particularly in specially controlled catalytic cracking processes), and secondly, that there exist well established old and new processes for combining isobutane with butylene. This is not meant to depreciate processes for making blending agents from the longer-chain hydrocarbons which have not yet had extensive application; they may have their commercial day in the future. It is also to be considered that alkylated fuels that have higher molecular weights than isooctane, no matter how well they are branched or rounded, do not have quite the same qualities; this is one of the reasons for preferring isobutane for alkylation purposes.

There is available a certain amount of natural isobutane in the natural gasoline which is recovered from gases issuing from oil and gas wells. This supply of natural isobutane is, however, far from sufficient to meet the demand, and the deficiency has to be met by subjecting normal butane to isomerization in the refinery.

The art of isomerizing normal butane on the industrial scale has had its chief development since the beginning of World War II. The isomerizing process is best carried out with the use of a catalyst, and in this case the preferred catalyst is anhydrous aluminum chloride, $Al Cl_3$. As was said above, there are eight isomerization processes known in the refining art. As regards the isomerization of butane, preference is currently given to vapor phase operation, in which the butane in gaseous form is passed through a fixed bed of catalysts; the temperature and pressure are controlled so that unreacted normal butane and the reaction product remain gaseous until they reach the debutanizer, where the unused normal butane is recovered and recycled.

As may be seen from the accompanying simplified flow sheet the principle of a vapor phase isomerization process is, in theory, fairly simple. The entering stream of normal butane first passes through a heater to be raised to the required temperature; some gaseous hydrochloric acid is added, and it then enters the reaction chamber (reactor) where a certain proportion of the normal butane is converted into the isocompound. The vapors from the reactor pass through a trap to recover suspended particles of the aluminum chloride catalyst (the temperature within the reactor is such that some of the aluminum chloride is sublimed). Next the gaseous mixture is passed into a tower where the mixture of isobutane and unreacted normal butane is condensed, while the hydrochloric acid remains in the gaseous form. The mixed butanes are separated by distillation; the normal butane is returned to the process and the isobutane is prepared for shipment to the alkylation plant. It is, of course, most convenient to have the isomerization and the alkylation plants close together at the same refinery. The hydrochloric acid figures in this process as a "promoter," which increases the activity of the aluminum chloride catalyst.

It appears that vapor phase isomerization was first used by the Shell Oil Company at a refinery in Trinidad. Later on, in October, 1941, this company put the process into operation at its Houston refinery, and the Shell vapor phase process was licensed to a number of other companies. Other inventors brought out variants of this vapor phase process. A variant developed by the Universal Oil Products Company has been installed in several refineries. Besides the Shell and the Universal Oil Products processes, there are other processes that have been installed or are undergoing development by the Standard Oil Company of New Jersey (Kellogg), Phillips Oil Company and The Texas Company. The intimate details of these vapor phase isomerizing processes are under the ban of secrecy imposed by the censors or by the patent situation. It is well known, however, that all of them employ aluminum chloride in the solid form as the catalyst, and all use hydrochloric acid for promoting the catalytic reaction. Though all these vapor phase processes work by the same principle and employ the same solid catalyst and catalyst promoter, they have different techniques in the details of pressure and temperature, feed rate, and manipulative control. In some, the operation is conducted strictly in the vapor phase; in others, there is a mixture of the vapor and the liquid phases. Since the effective life of the catalyst is not indefinitely long, the process is necessarily intermittent. After a run the reactor is shut down and the catalyst is removed for rejuvenation. Continuous production may be assured by having two reactors, so that one may be functioning while the other is shut down.

The average efficiency of conversion in the vapor phase isomerization processes, that is, the proportion of isobutane produced per pass, is said to be of the order of 40 percent of the entering feed. This limit of efficiency is determined largely by mass action or equilibrium relations; that is, there is a thermodynamic or chemodynamic condition which dictates that only a certain proportion of the normal butane can be isomerized per pass under the chosen operating conditions. Besides this equilibrium requirement the efficiency of the vapor phase processes is affected by other phenomena inherent in the nature of the substances and the working conditions. Under the working conditions of these processes it seems

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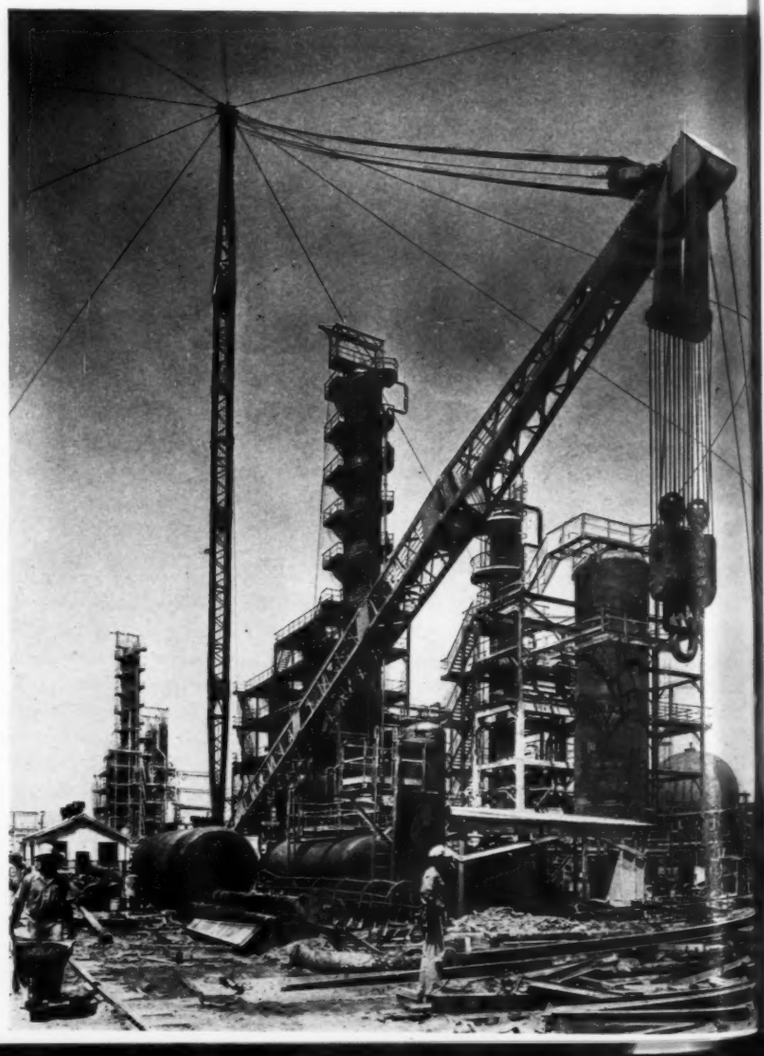


An alkylation plant in process of erection. Such plants utilize isomerized isobutane as part of their essential raw material.

WAR'S IMPACT
on Pacific Coast Industry

Activities of Standard of California in Supplying Military Needs Illustrate the Great Transformation That Has Taken Place in Operations.

BACK in the palmy days of 1938, the Standard Oil Company of California ran a friendly little message to its customers in the informal newspaper column it conducts in a number of metropolitan newspapers. "Sorry—but we're fresh out of gas!" was its jocular title, and its theme was the then assumed impossibility of ever driving up to a Standard station only to be told you couldn't have all the gasoline or oil or anything else Standard service could give you.

Since December 7, 1941, Americans have seen so many impossibilities become fact, that restricted use of gasoline and tires are minor discomforts.

But the company's word still stands. Its major customer now is a big determined fellow in a high hat and red and white striped pants; he gets all the gasoline, oil and thousands of other petroleum products he orders . . . and right away.

Because of its size and the broad scope of its operations Standard of California's activities in supplying materials for military use are more varied and result in a wider variety of products than is the case with many of its neighbors but in all other respects its example is typical of the way in which the entire West Coast industry is devoting its resources and energies to meeting the tremendous demands of war, and particularly of the war in the Pacific.

The Army-Navy "E" which floats over the company's Richmond Refinery is symbolic of the manner in which its facilities and its big organization are concentrated on the business of war, delivering fuels, toluene, lubricants, butadiene and numberless other products urgently needed in the United Nations' fight.

Major war projects financed wholly by the company in the field of manufacturing operations alone, many of them initiated long before Pearl Harbor, represent an investment of $36,668,300. More than four millions of this sum will be spent this year in expanding the company's war program.

Included in the investment is the cost of Standard's 100 octane aviation gasoline program, which was started at a time when isooctane was still a laboratory curiosity, and engines capable of fully utilizing such fuel were scarcely more than an inventor's dream.

Research was conducted for several years. Before 1940, Standard invested $3,755,000 for hydrogenation, polymerization and alkylation plants. As the Army and Navy, virtually the only customers for the 100 octane product at that time, did not utilize all of it, the company built up a reserve supply which proved welcome in the first few months of the war, before expanded production got under way.

Since 1940 $10,072,000 more of Standard's money has gone into 100 octane projects, bringing the total capital expenditure for this program to $13,827,000. Included in present operations is a hydrogenation plant, two alkylation plants, two isomerization plants (one under construction) and a $5,384,000 Houdry catalytic cracking unit. The latter was started before the Pearl Harbor attack and was intended originally for production of other types of gasoline as well as the 100 octane type, but was altered during construction to meet the war's increased need for the aviation gasoline.

Construction starts soon on a government-financed $13,500,000 plant which Standard expects to be operating by next year, increasing again the 100 octane fuel output. Catalytic cracking and retreating units, and an isomerization and an alkylation plant will be included in the project.

Almost as important as weapons in this war is rubber. Standard is constructing a $6,200,000 butadiene plant, financed by the government, at one of its refineries. It will be completed this autumn. Enough synthetic rubber to make several million tires a year can be made of the butadiene produced here.

Fuel and lubricating oils represent another important channel for Standard of California war activities.

The company's entire lubricating oil program represents an expenditure of approximately ten million dollars, made exclusively from its own capital, and without a government guarantee. As with 100 octane aviation gasoline, the company began its development of RPM Delo, its Diesel engine lubricating oil, long before the war made this product a "must" for our fighting forces on the sea.

At first utilized chiefly in tractors this oil was found to be an ideal lubricant for submarine engines. Because of its solvent properties it permits uninterrupted operations in internal-combustion engines such as those in submarines and surface warships.

With the advent of the war demand for this oil doubled almost immediately. As a result, Standard has constructed additional facilities at a cost of $4,945,300 to increase production of the Delo type lubricating oils. Included are distillation units, a solvent refining plant, a dewaxing plant and equipment for the production of additives.

The company also is supplying large quantities of fuel oil for destroyers, battleships and other vessels, and has greatly expanded production, storing and loading facilities to meet Navy requirements.

Toluene for "block-busters" is being manufactured by Standard of California in a plant which cost $782,000 and which was financed wholly by the company. It includes a unit for manufacture of the catalyst used in the process.

"The chemistry of World War I was based on coal-tar; that of this war on petroleum," H. D. Collier, president of Standard of California pointed out not long ago. To enumerate all the products which the company is manufacturing now, either directly for the armed forces or to fill one of the many shortages caused by the emergency, would fill a volume; so would an account of all the chemical studies which are still in the research stage. A petroleum-derivative which can be used as a substitute for quinine is one example, of many, among the petroleum-derived drugs which are subjects of research at present.

Two of the many products which are being made in large quantities by Standard for the armed forces, are cresylic acids and naphthenic acids. One hundred percent of the country's supply of cresylic acids is now being used in the war, and the demand is still mounting. The shortage would be still more critical had not petroleum chemists determined that these acids could be obtained from petroleum. Fields in which the cresylics are used are as widely varied as they are critical. They are utilized to provide an insoluble resin for plywood for prefabricated houses in defense areas and evacuation centers, and in disinfectants and germicides.

The naphthenic acids have many military uses: as bases for paint-dryers, for impregnating camouflage cloth, thus preserving fibers against molds and fungi, and also for the flotation process for recovering magnesium from low-grade ores.

Pre-treatment with naphthenic acids of sand-bags used as protection in bombing attacks was found in England to save the bags from rapid deterioration, and military authorities in this country now demand that sand-bags, camouflage cloth and similar fabrics be treated in this manner. Copper naphthenate also is used in shipbottom paints, as it destroys marine organisms attaching themselves and thus retarding the ship's speed.

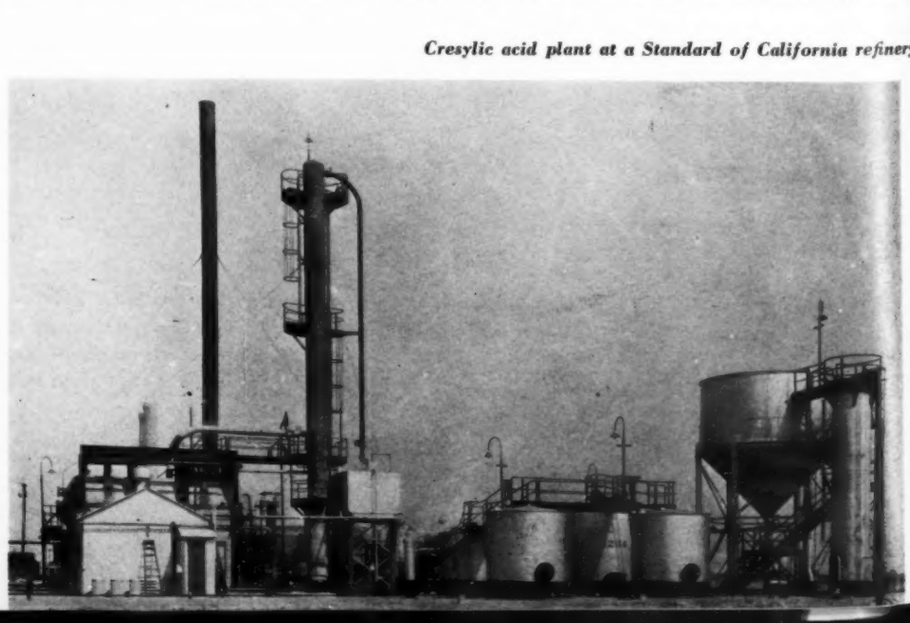
With the war's increasing demand for petroleum to serve in all its theatres, Standard of California has expanded its exploration activities.

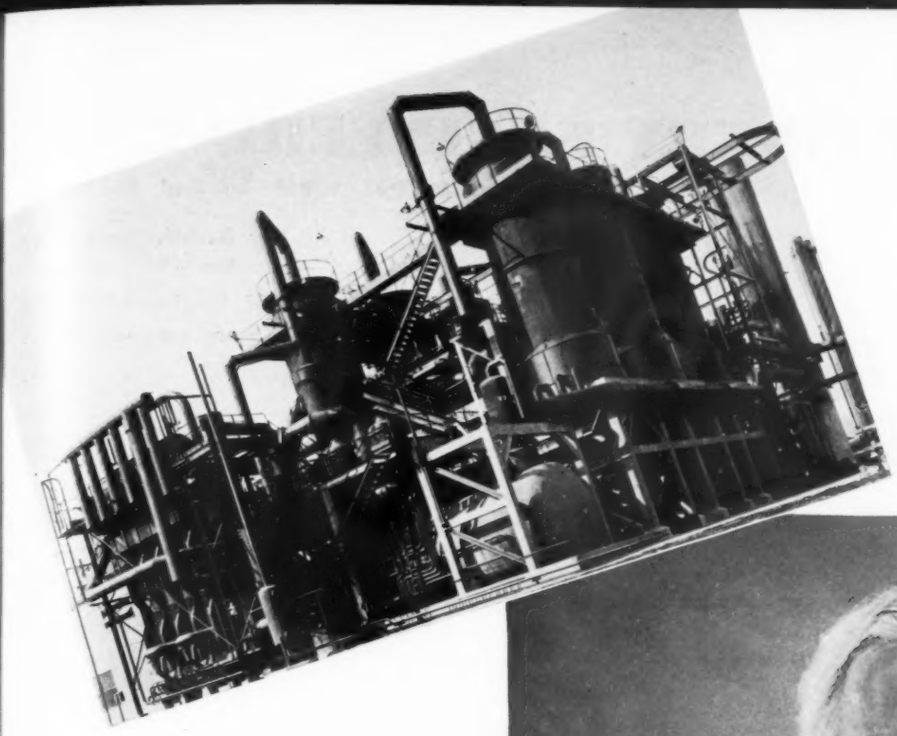
"We expect to drill 365 wells in 1943—an average of one a day," said President Collier recently, and the company's producing department backs his statement with a program calculated to meet it.

Production in one month alone recently was 140,332 barrels of crude oil a day, or 44 percent increase over the same month for the previous year, and every effort is being made to step up production.

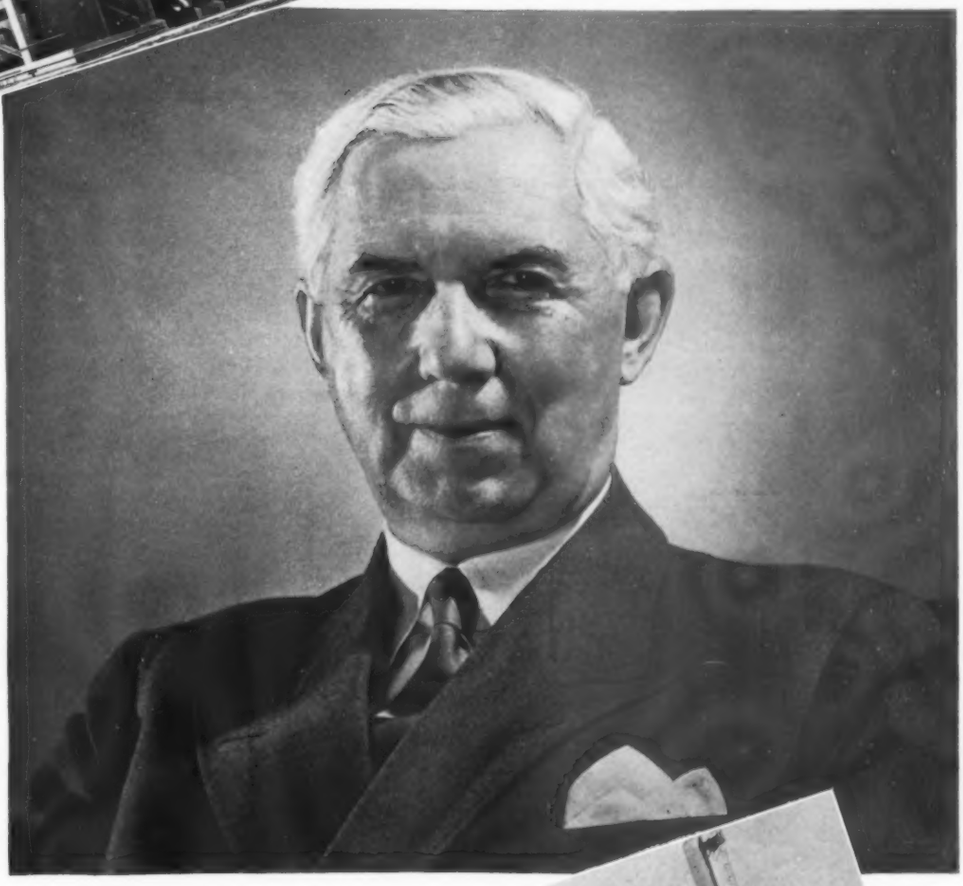
Accelerating drilling progress, the company is drilling a number of shallow wells in order to get types of crude high in fuel oil yield, as well

Cresylic acid plant at a Standard of California refinery.





The man-power problem caused by the war has found a happier solution than might have been believed possible a few years ago, in the employment of women. Thirty-five hundred women now perform tasks ranging from elevator operators in the home office, to pumpers in the field and still-operators in refineries. Standard Stations, Inc., finds women highly efficient as station salesmen and managers. Special labor-saving devices have made it possible for women of average strength to change tires, fill grease-guns, lubricate cars and perform assignments heretofore filled by men, with the exception of changing batteries.



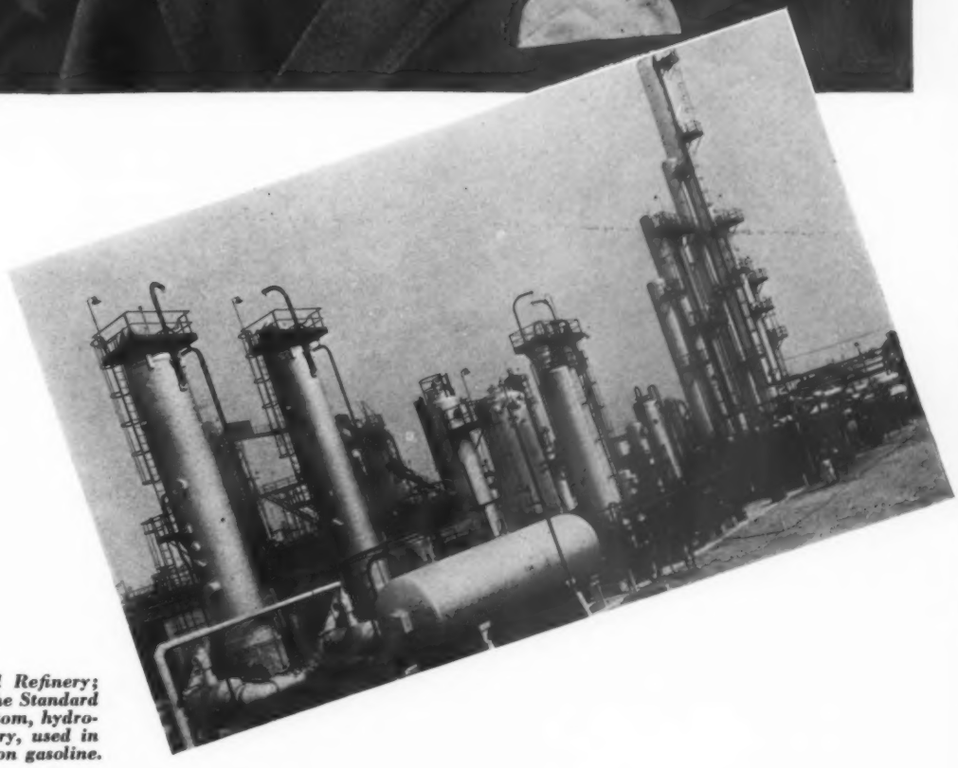
as crude which will give gasoline suitable for high octane aviation gasoline.

In drilling these shallow wells, Standard is using spark plug and mast drilling outfits. Such outfits, with internal combustion engines instead of the steam powered type, and masts instead of the conventional derricks, save time and material in preparing locations, rigging up and tearing out.

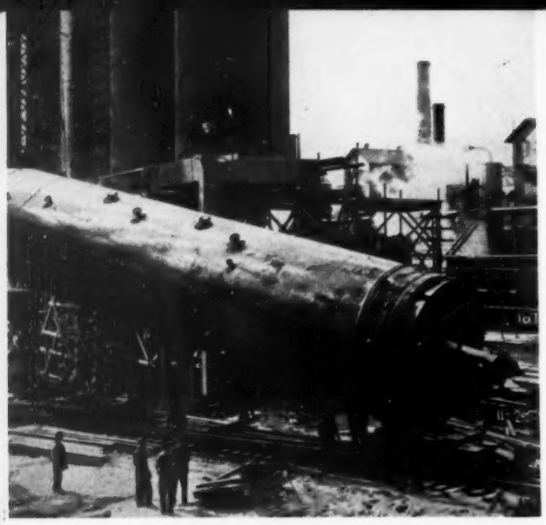
On completion of the shallow wells, a floor type pumping unit is used, and the wells are serviced with portable outfits. All this portable equipment means a large saving in critical materials as well as in time. The company is using three such portable drilling outfits in the Coalinga area and five in the Midway-Sunset area; three in the Kern front and Poso Creek areas, and several in the Los Angeles basin in the Montebello and Huntington Beach areas.

The war has accelerated Standard's natural gasolene activities. Thirty-six absorption and compression plants for natural gasoline are situated in the hearts of the various oil fields, where production of iso-butane trebled production in 1941, and in 1942 quadrupled the production of 1940. These plants produce not only iso-butane but a large quantity of normal butane which is being used in the war industries, for heating Army camps and for conversion at isomerization plants into iso-butane. Other processes will enable conversion to butadiene next fall, when the butadine program is opened.

Pipeline capacities are being expanded in order to release more tankers for war duty, and crude oil is now being carried by pipeline wherever possible. The Stanpac pipeline which carried natural gas before the war, is utilized now for transportation of crude, and Standard is sharing the line with other oil companies of the vicinity as an emergency measure.



Top: Houdry plant at a Standard Refinery; center, H. D. Collier, president of the Standard Oil Company of California, and bottom, hydro-polymer plant at a Standard refinery, used in the production of 100-octane aviation gasoline.



110-ton pressure vessel being hoisted into position at catalytic cracking plant by use of gin poles.

REFINERY ENGINEERING
Serves the War Effort

By J. W. McAneny
The M. W. Kellogg Co.

Past Experience and Pilot Plant Practice Prepared Engineering and Contracting Firms for Producing Vast New Units of Complex Character.

[IN EVALUATING the oil industry's remarkable contribution to the steadily growing effectiveness of the United Nations' war machine one essential fact needs to be kept constantly in mind. The record already established and the further advances which will make themselves known as the conflict progresses would have been impossible except for the vast amount of effort directed by the industry in the years before the war to the improvement of its methods and its products. Processes that were in the stage of incubation at the commencement of the struggle have been speeded up and brought to practical application. An army of technical experts working in elaborately equipped laboratories have attacked new problems and have met new demands as they have arisen.

Keeping pace with the creative activities of the oil companies has gone the work of the industry's great engineering and construction firms with their own well-equipped organizations for research and testing. These have originated many important improvements and have provided the equally valuable service of translating into utilitarian form the ideas generated by scientists and inventors. Some of the activities of one such leading engineering firm are outlined briefly in the accompanying article.—ED.]

Before the outbreak of World War II, there was little incentive from an economic standpoint for a refiner to make the huge initial investment and to assume the increased operating cost necessary to produce high-octane aviation gasoline. The aviation industry had not yet progressed to mass production methods and the majority of the aviation engines produced did not require a super-fuel to reach peak performance. This was the situation when hostilities broke out in Europe. Governmental agencies, realizing that because of lend-lease and defense commitments the United States would require vastly increased quantities of high-octane aviation gasoline, stimulated interest in the expansion of the aviation program by creating, for the first time, a commercial market attractive to refiners from a volume and economic standpoint.

Many of the major refiners, seeking to enter this new market which gave every promise of continued growth as aerial warfare increased, sought technical guidance from The M. W. Kellogg Company as to the method and equipment to be employed, recognizing the extensive study the company had given to the subject. That the company was prepared to answer this demand for experienced technical counsel is indicated by the number and variety of Kellogg plants erected or now under construction throughout the nation.

Groundwork in the preparation for this phase of war against the Axis, had been laid as far back as 1919. The Model T Ford was then in its hey-day. Gasoline refining consisted of heating crude oil and cracking gas oil in shell stills and cooling the gasoline in water condensers. Octane number was still an unborn term, and crude oil itself was considered an inexhaustible resource.

No chemical engineering data on the refining of petroleum existed, nor was there a single organization in the country engaged in the design and building of refining equipment. A refiner who wished to repair a worn-out shell still or increase his production by adding another still to his battery merely called in the refinery plate and pipe shop crews. They were quite capable of constructing the basic refining unit, the simple shell still, without benefit of engineer or blueprint.

This was the refining picture when The Kellogg Company, already firmly established as a fabricator and constructor of heavy equipment, and foreseeing that the wasteful refining practices then in vogue could not continue in the face of diminishing crude resources and increasing demand for motor fuel, made the pioneer effort to introduce technical skill into petroleum refining. Patent and licensing rights to the historic Fleming Process, a refinement of the existing shell still technique, were secured and offered to the industry. Although pathetically crude when judged by present-day standards, the Fleming Process, nevertheless, represented the first advance in refining practice in years and was seized upon eagerly by forward-looking refiners. Its success marked the beginning of the engineer-contractor era and established Kellogg's position in the new-found industry.

Some four years later the company secured the licensing rights to the Cross Cracking Process. This process, which utilized the principle of heating oil in pipes or tubes to increase yield of gasoline from crude, was the foundation of all thermal high pressure cracking processes, which dominated the industry until the development of catalytic cracking in the last few years. The Cross Process interjected an entirely new basic idea into refining, and its success was instantaneous. The death knell of the shell stills had sounded. In the face of decreasing profit margins and increasing gasoline demands, the wasteful shell still operation could no longer compete with the new thermal cracking units, which doubled the yield of gasoline from crude.

The necessity for modernization of refineries stimulated interest in research work on petroleum, and variations of the basic thermal cracking process were forthcoming rapidly. It soon became apparent that Kellogg could no longer depend on the efforts of individual inventors to maintain its leadership on process design, chiefly because refining research had advanced to the point where the financial investment in material and labor was beyond the reach of an individual.

Realizing that further advances must stem from the efforts of organized groups of technicians and engineers rather than from individuals, Kellogg decided to establish its own petroleum laboratory. The acquisition of the laboratory and its attendant staff of technical experts filled in the last gap in Kellogg's chain of services to the industry. The company stands today as a completely integrated engineering-contracting organization capable of handling all functions connected with refining units from inception of process to operation of the completed plant.

The Kellogg laboratory is unique in that it contains pilot plants, representing every type of process connected with refining, whose parts have been designed with such precision that the operating data from these semi-plant scale units correspond exactly with those which are obtained from a full-sized plant. The advent of pilot plant operation resulted in two major advancements in refining technology.

As mentioned before, no chemical engineering data upon which to base process design existed prior to 1919, and in pioneering the refinery building industry, Kellogg was also forced to pioneer the accumulation of design data. In the early years such data were painstakingly obtained through the medium of test runs on units after they had been erected. With the perfection of the pilot plants, on which operating conditions could be varied at will, chemical engineering data on process design were obtained on all varieties of crudes under every possible combination of operating conditions. During the bleak years of the depression, the pilot plants ran on a 24-hour basis, piling up data which were to serve as Kellogg's stock-in-trade in the recovery years, when refinery modernization was rampant.

The accuracy with which pilot plant data could be reproduced in full-scale plants introduced a new concept into process design. Heretofore the refiner was sold a standard process and he was required to fit his crude resources and product requirements into the standardized design as best he could. Through the medium of the pilot plant it was now possible to design a process to fit the specific requirements of the individual refiner.

The new catalytic refining plants, which are rapidly replacing thermal processes in many refineries, are based on design data provided by pilot plant runs. The wonders of this new petrochemical industry have been too well publicized to require further comment here. Suffice it to say that the use of catalyst in refining has made it necessary to re-write text books on organic chemistry by accomplishing reactions which were pronounced impossible twenty years ago.

As was to be expected from an organization with a background of experience which extended back to the early days of refining, Kellogg had been instrumental in the development of commercial processes for the manufacture of high-octane aviation gasoline. When the country called for an expansion of the 100-octane gasoline program, the answers were already at hand.

Chief among these new processes is Fluid Catalyst Cracking, which yields an excellent base stock for aviation gasoline and provides butylene as a secondary product.

Butylene and isobutane serves as the raw materials for the alkylation process for the manufacture of alkylate, a highly desirable blending material for aviation gasoline formed by the joining of a butylene and an isobutane molecule as a result of catalytic action.

The limited quantity of isobutane available and the demand for increased alkylate production led to the development of still another catalytic process, isomerization of normal butane to isobutane to provide additional feed stock for alkylation plants.

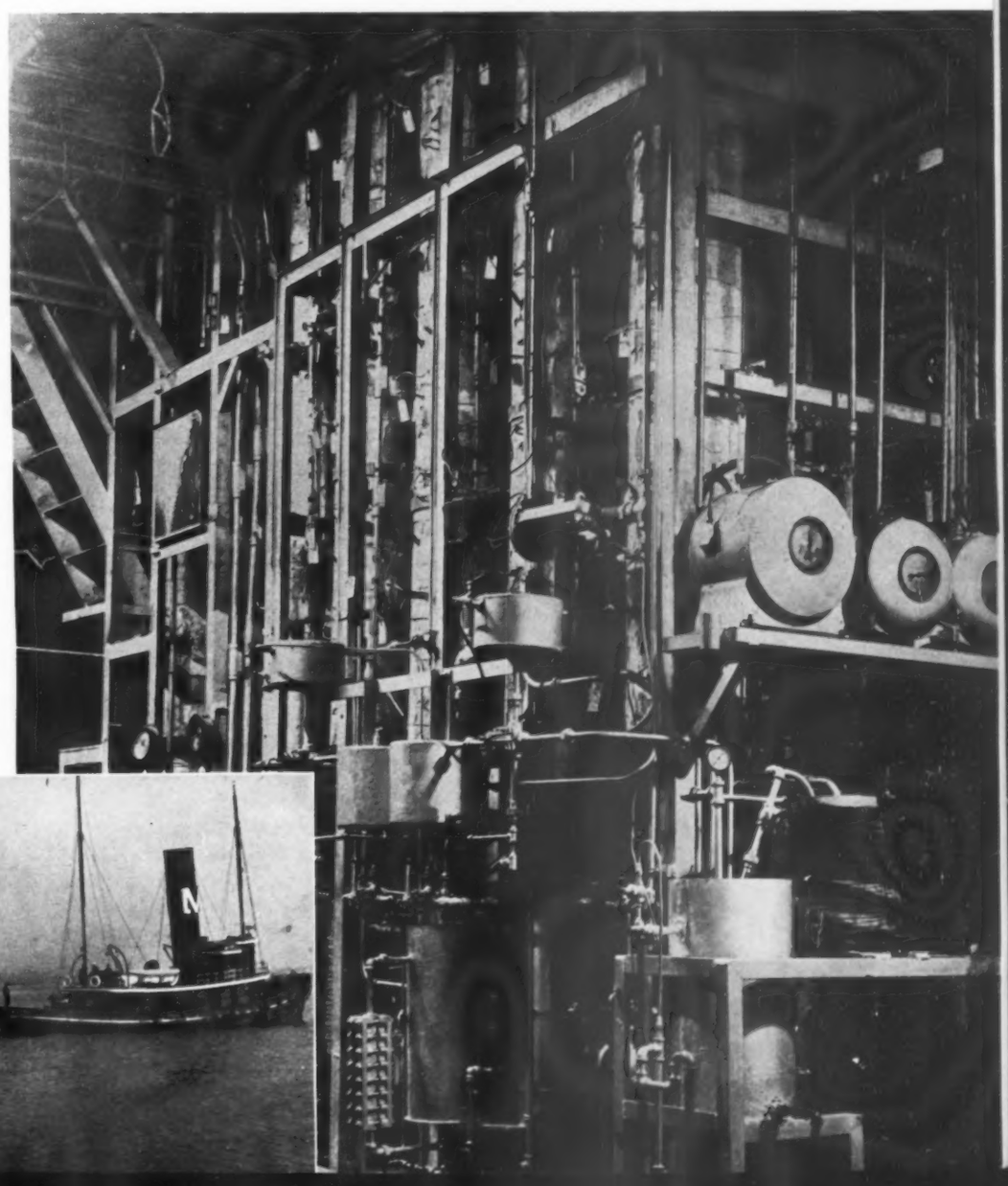
As indicative of the share of the aviation gasoline expansion program with which Kellogg has been entrusted, it may be stated that the combined output of the Kellogg fluid catalyst, alkylation and isomerization plants now under construction in the United States, Canada, and abroad, will represent between thirty and forty percent of the contemplated requirements of the United Nations.

The limited supply of toluene, the basis of high explosives, was another bottleneck which had to be broken for the successful prosecution of the war. Kellogg pioneered the development of the process by which toluene is obtained from petroleum by catalytic hydroforming. The output of the Kellogg toluene plants has resulted in a tenfold increase in the peacetime output of this product, formerly obtained as a coal tar industry by-product.

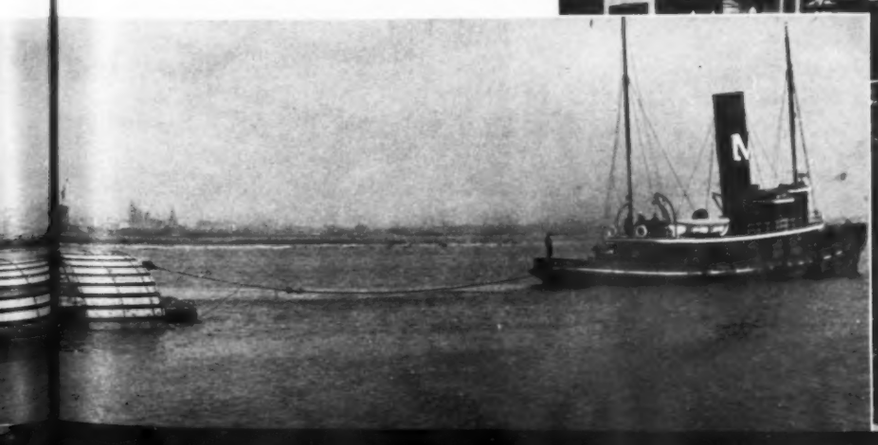
In addition to the enterprises directly connected with petroleum refining, Kellogg's organization and facilities have been pressed into service to help solve production problems in other war industries. Among such projects may be listed the design and erection of plants for the production of butadiene, the base of synthetic rubber; of electrolytic magnesium, required in tremendous quantities by the airplane industry, where it is combined with aluminum to produce an alloy of great strength and light weight; of ammonia by gas synthesis, a basic raw material in chemical war industries; and of synthetic catalyst, the cornerstone of the new "petro-chemical" industry.

Although facts and figures on production must necessarily remain a military secret until victory is won, when the record of accomplishment is finally made public, it will be found that the Kellogg-built plants have contributed in no small measure to the downfall of the dictators.

Portion of hydroforming pilot plant used in design of toluene process at Kellogg Jersey City laboratory.



250-ton tower at start of 1300-mile trip from Jersey City to Chicago under tow.



Texas Plant Holds Leading Place in Production of Petroleum Supplies for War

IN the extent and variety of the products which it is supplying for military use and as a result of its rapid expansion during the past few years the Baytown refinery of Humble Oil & Refining Company ranks as a leading petroleum war production plant of the nation. The development which has brought it to this position dates back to 1937, in which year a building program was started which has been almost continuous and which has altered the skyline of the plant tremendously.

Although it had experienced a steady and comparatively fast growth from the time of its founding in 1919 to 1937, it was in the latter year that Humble began the addition of equipment which today means so much to America at war. Not only were several important units constructed in that year, but also there was laid a unique 200-mile pipe line from the East Texas field to the refinery which was destined to play an important role in the plant's development. The original purpose of this line was to bring in a commingled stock of butane and natural gasoline for conversion into motor gasoline at the thermal polymerization unit constructed the same year. Today, this line supplies much of the raw material which makes up the war products stream.

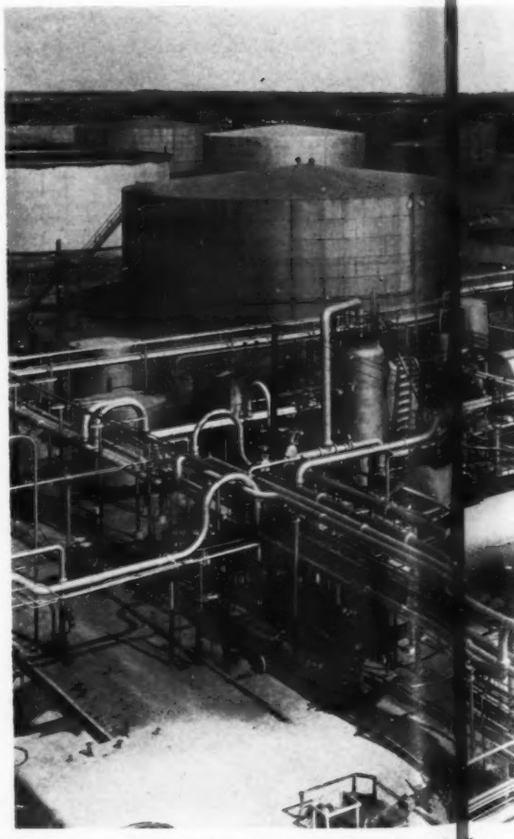
Also in 1937 Humble constructed propane and phenol treating plants to increase the output of high quality motor oils. Those units today have taken their place in the war production picture, turning out vast quantities of high quality aviation engine oils and heavy duty lubricants. In 1938 there was placed in operation still another unit which today is playing a tremendously vital role in war production. This is the world's first commercial alkylation plant, created by converting a cold acid polymerization plant. This unit for several years has been utilizing the isobutane separated from the natural gasoline delivered by pipe line from East Texas and the butylenes recovered from refinery gases to make alkylate, an essential blending agent added to base stock to make 100 octane gasoline.

Alkylate has been the backbone and a main limiting factor of the entire aviation gasoline program, but because of Baytown refinery's extensive facilities for the recovery of light ends, production of alkylate is more than enough for the refinery's aviation gasoline program. Moreover, Humble has increased the quantity and quality of its base stock by a new superfractionating unit completed last year, and further gains will be made from the operation of two catalytic cracking units, one of which is in operation while the second is under construction.

In addition to present facilities for the manufacture of aviation gasoline, it is understood that Humble has under consideration the conversion of certain existing facilities and the construction of others to increase materially the output of 100-octane gasoline and components. Another vital war production unit is Baytown Ordnance Works, the first of several government plants built adjacent to the refinery proper.

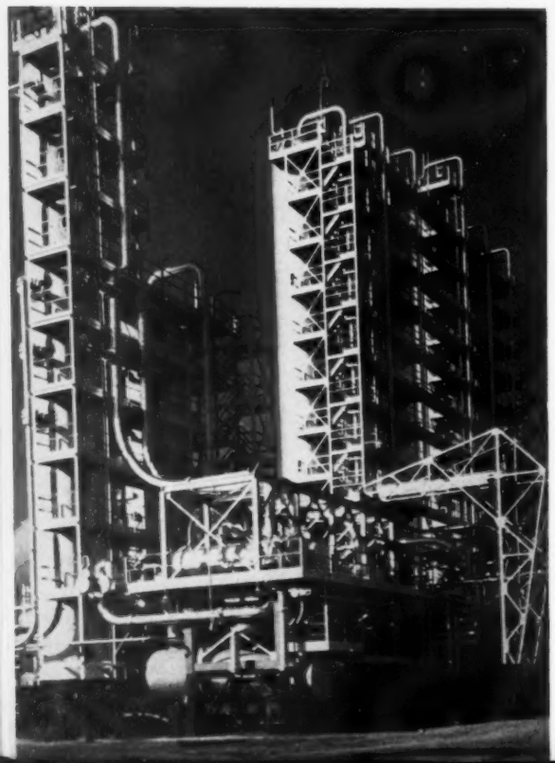
The process used in this plant for the manufacture of synthetic toluene had been perfected long before America's entry into the war, and the contract for the plant was signed on October 21, 1940. Construction was completed ahead of schedule, the plant was operating for several weeks before Pearl Harbor, and since September, 1942, production has been consistently more than double the contract rate. The plant, it was recently announced, produced during 1942 more than twice as much toluene as was produced in the country from all other sources, giving it the distinction of being the nation's Number 1 petroleum ordnance plant. It was for this outstanding production accord that the plant was awarded the Army-Navy E flag for, in August, 1942, and a star for continued fine performance early this year.

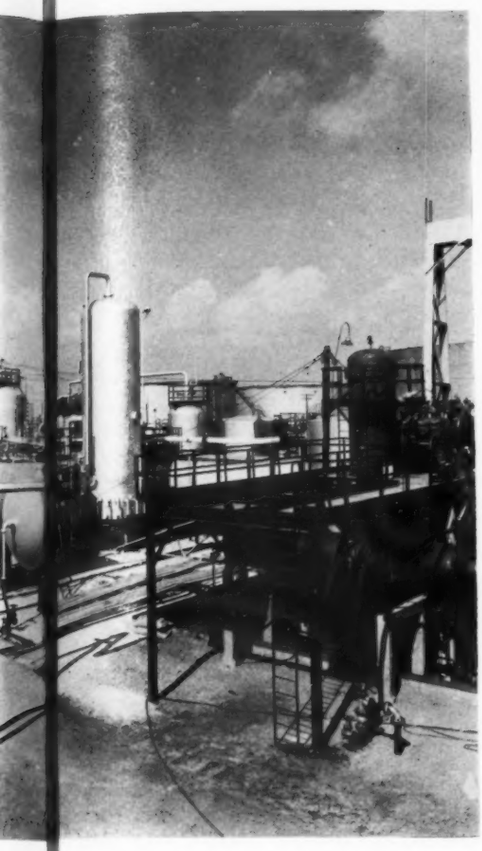
The third major war production assignment being handled by the Humble Company at Baytown is a big share in the synthetic rubber program. Construction is nearing completion on a 30,000-tons-a-year Butadiene plant, and a Butyl rubber plant of the same capacity is scheduled

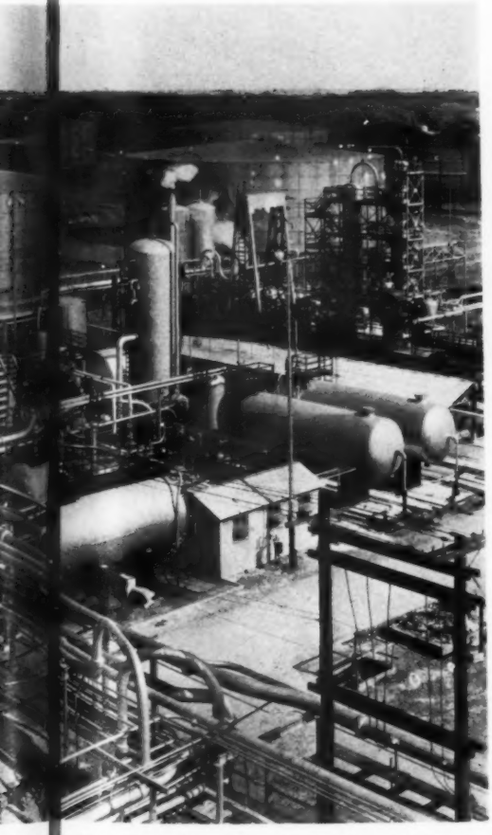


Top: First commercial alkylation plant built in [illegible]bove: this country.

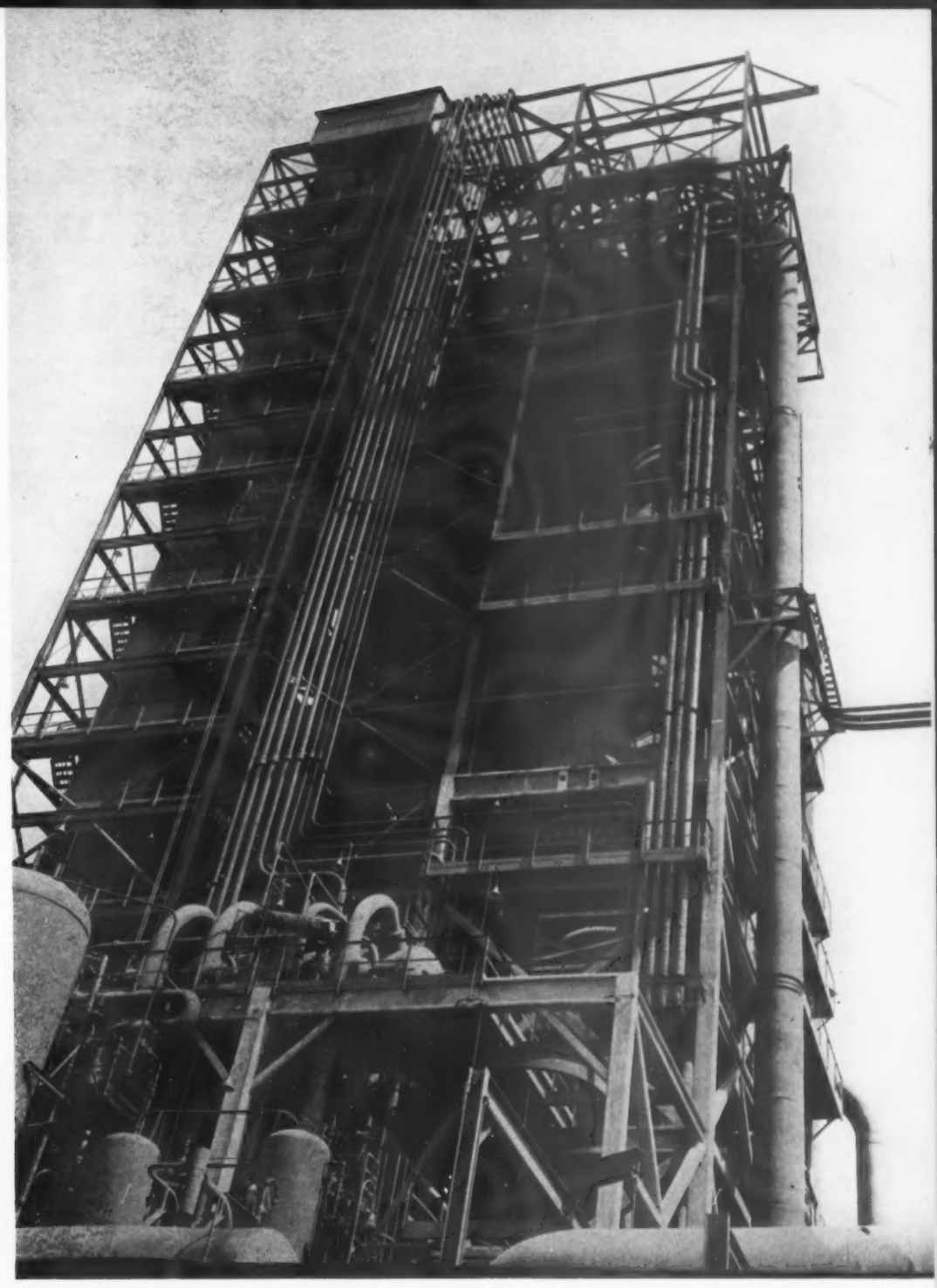
Light ends fractionating unit, one of the many Baytown units playing an important part in making components for critical war products.







uilt in above: ***Alkylation plant at Baytown, producing alkylates for 100-octane gasoline.***



Fluid catalytic cracking unit at Baytown, one of three of its kind in the United States.

to begin production late this year. The contract for the Butyl rubber plant was signed May, 1942, after construction had already been started on the Butadiene plant which had been contracted for several months earlier. Both the rubber plants and Baytown Ordnance Works are government financed plants, but all three draw raw materials from new and converted units at Baytown refinery, built and financed by the Humble Company in recent years.

While aviation gasoline, toluene and synthetic rubber are Baytown's principal war products, there are others of considerable importance. Navy fuel oil and Navy Diesel fuel, special Navy lubricants, and aviation gasoline components are also produced in considerable volume, bringing the refinery's total output for use by the armed services to approximately 30 percent of the total daily run. The greater portion of the other 70 percent goes directly to essential industries and war plants on the home front. Humble also has a small refinery at San Antonio making 91 Octane aviation gasoline for training planes. At the company's Ingleside plant, a refinery conversion project will soon be completed for the manufacture of butadiene. This plant likewise makes 91 Octane aviation gasoline, 100-Octane aviation gasoline base stock, and some special Navy fuels.

CATALYSTS

Have Important Role

IN WAR INDUSTRY

By A. W. TRUSTY

Chief Chemist,
Arkansas Fuel Oil Company

Noteworthy Advances in Petroleum Refining and in Many Chemical Processes Have Resulted from Discovery of Catalytic Agents That Speed Reactions and Improve Products.

SO NUMEROUS are the applications of catalytic action in the present day chemical industries that a large volume would be needed for a detailed treatment of them. The rapid extension of catalytic methods has been spurred on by the unprecedented demand for both quality and quantity of products. The purpose of this article is to describe in a general way how the principles of catalytic action are being applied in practice.

A catalyst has been defined as a substance which, without appearing in the final product, influences the velocity of a reaction. Some cynical worker has compared a catalyst to a plant foreman—a substance which does no work, but no work is done if the substance is not present. For example, a mixture of hydrogen and oxygen is stable at ordinary temperatures, but the introduction of a piece of platinum black causes immediate explosive combination; the platinum black is not visibly affected and can repeat the same effects indefinitely.

As another illustration of recation speeded up by a catalyst; hydrogen peroxide decomposes very slowly in cold water solution, a 30 volume solution requiring more than 240 hours at 63° F. for 50 percent decomposition, but the addition of 0.06 grams of platinum black to 20 c.c. of such solution causes a vigorous evolution of oxygen and reduces the time for half decomposition to eight seconds at 57° F. The platinum black, which does not seem to be altered, has by its presence enormously accelerated a reaction which normally takes place spontaneously but very slowly.

Many substances are capable of assisting in chemical reactions; elements, oxides, mineral acids, bases, metallic halides, ammonia and its derivatives, and various organic compounds.

Fermentation of grain is a catalytic action, so it is obvious that catalysis has played an important (although unrecognized) role from the earliest times in the production of alcoholic liquors, vinegar, and other simple commodities of this type. The first scientific observation of a catalytic change was in 1811 when Kirchhof showed that mineral acids, in hot water solution, change starch into dextrine and sugar, without being themselves altered by the reaction.

Although catalytic changes were first so designated by Berzelius about the year 1835, they were recognized much earlier, and catalysts were used in preparing chemical products several centuries before that date. For example, the production of ether by the action of sulfuric acid on alcohol was familiar to the alchemist. In 1740 Roebuck and others introduced the chamber process for manufacturing sulfuric acid, in which large amounts of sulfur dioxide were oxidized to sulfuric acid by the use of comparatively small proportions of nitrogen. Within recent years a number of works have been published on the reactions of various compounds with various catalysts under various conditions.

Certain materials have been found to decrease the normal rate of chemical action, or, in some cases even stop the action completely. In the manufacture of sulfuric acid by the contact process the presence of vapors of mercury, phosphorus, and particularly arsenic in the gas is sufficient to impair rapidly and finally destroy the catalytic action of the platinized asbestos. In the use of finely divided nickel as a catalyst for direct hydrogenation, traces of chlorine, sulfur, bromine, or iodine, either in the metal, in the hydrogen, or in the substance to be treated, act as poisons and quickly kill the action of the catalyst. It has long been known that hydrogen peroxide keeps better when slightly acid. Thus at 149° F., pure hydrogen peroxide requires 3.2 hours for 50 percent decomposition, but the addition of .026 molecule of hydrochloric acid will increase the time for the same amount of decomposition to 35 hours. In the very complex reaction of the vulcanization of rubber, in which a large number of substances have a beneficial effect, phenylhydrazine is a very marked negative catalyst.

According to circumstances, catalysts are frequently able to work in inverse directions. Platinum, nickel and copper are thus catalysts of hydrogenation or dehydrogenation as the case may be. Reduced copper will hydrogenate aldehydes to alcohols at 356° F., but will reverse the reaction at 482° F. to dehydrogenate alcohols to produce aldehydes.

Temperature is an important factor in many catalytic reactions, just as it is in most chemical changes. In a large number of cases, the reaction velocity of a chemical reaction is doubled for each 18° F. increase in temperature. Reactions involving catalysts follow this general rule. A rise in temperature usually accelerates the velocity, so long as the mechanism of the reaction is not changed. This, however, frequently happens; thus catalytic hydrogenation is sometimes replaced above a certain temperature, by its reverse, catalytic dehydrogenation.

For example, in the hydrogenation of benzene over nickel, the velocity of the formation of cyclohexane increases rapidly from 158° F., where it is very slow, up to 356-392° F., the most favorable temperature. From there on it decreases as 572° is approached, at which this reaction no longer takes place, cyclohexane being, on the contrary, decomposed into benzene and hydrogen or even into benzene and methane:

$$3\,C_6H_{12} = 2\,C_6H_6 - 6\,CH_4$$

The latter reaction is more pronounced as the temperature is raised.

By a choice of reaction temperature, it is often possible to obtain various products. For example, in the hydrogenation of anthracene over nickel:

Temperature	*Product*
360° F.	Perhydro-anthracene ($C_{14}H_{24}$) and dodecahydro-anthracene
392° F.	Octohydro-anthracene
500° F.	Tetrahydro-anthracene

There are many reactions and catalysts that are used today, but they may be divided into two general types: (1) In a homogenous system, where there is intimate mixing of the various constituents, as in the use of sulfuric acid with hydrocarbons for the manufacture of alkylate in the alkylation process. (2) In a heterogeneous system, where, for example, a solid catalyst is brought into contact with a gas or liquid.

Solid catalysts are more active the greater their surface, and for the same weight, the finer their grains, but there is by no means a direct relationship between the activity and the extent of surface. The method of preparation plays an important part in the activity of the catalyst. Platinum black is an efficient agent when prepared by heating below 572° F. If it is heated to 806° F. it is considerably weakened. Heated to 932° F. it loses all activity. Nickel metal in sheet or thin foil possesses only slight activity. Catalytic nickel should be prepared by reducing the oxide by hydrogen or carbon monoxide. The metal so produced is readily oxidized and frequently pyrophoric; therefore, the metal should be reduced in the same apparatus in which it is to be used, or precautions should be taken to

cool the reduced metal in hydrogen or nitrogen. The amount of chemical change that can be brought about with a certain quantity of catalyst varies widely. In some of the organic chemical processes in which the catalyst itself is apt to become altered by side reactions the amount of chemical change may only be 50-100 times the weight of the catalyst itself. At the other extreme we have instances such as the use of platinum gauze in the oxidation of ammonia, where with suitable precautions the life of the catalyst is practically indefinite and the rate of transformation exceedingly great. For example, a piece of platinum gauze six inches by four inches is capable of producing about 12 pounds of nitric acid per hour.

Water frequently is a positive catalyst. Carbon and even phosphorus refuse to burn in perfectly dry oxygen. In the catalytic oxidation of methyl alcohol vapors by a platinum spiral, the presence of water favors the production of formaldehyde. With absolute methyl alcohol, incandescense is not produced unless the spiral has an initial temperature of at least 752° F., while with 20 percent of water in the alcohol, 347° F. is sufficient.

In the petroleum industry the best known catalytic cracking process is the Houdry, in which the cracking is performed while the oil is in contact with a solid catalyst consisting of activated hydrosilicate of alumina. To do away with the necessity of multiple chambers in order to permit revivification of the catalyst at frequent intervals a "fluid catalyst" has been evolved. The catalyst is made to flow like a liquid, and when spent, is made to move out of the contact zone to a revivification zone, whence it is continuously fed back to the catalyzing zone. One of the latest developments in this field is the "bead catalyst" described elsewhere in this issue.

The advantages of the catalytic cracking process over the non-catalytic thermal cracking process is the production of a high octane gasoline of aviation grade with high yield (45 percent) in one pass, low gas production, no production of heavy fuel oils, and flexibility in products which may be produced for seasonal markets.

There are several important applications to which catalytic cracking adapts itself. An interesting new development is the manufacture of the butadiene in a single stage from butane as a feed. The physical equipment for this process is very similar to the equipment needed for gasoline manufacture. The yield of butadiene is reported to be high and the operating temperatures are lower than in the conventional thermal cracking operation for the production of this gas. Another use of the Houdry process is in the manufacture of ethyl benzene by passing ethylene and benzene continuously through a two-case catalytic converter.

The alkylation process for the production of high octane gasoline is the result of the discovery that paraffin hydrocarbons in the presence of a catalyst unite with olefins. Commercially, isobutane and butylene meet in the presence of 96 to 100 percent sulfuric acid at temperatures of about 40° F. (Hydroflouric acid is used as the catalyst in a number of plants.) The resulting alkylate has an octane number over 90, and may be blended with tetra-ethyl lead and other blending stocks to make 100 octane aviation fuel.

The Universal Oil Products Company has installed a large number of plants of this type, whereby a gas containing unsaturates is passed over a phosphoric acid catalyst at a temperature of 450° F. and under a 200-pound pressure. A number of these plants have been used since the war to make dimer, which product is subsequently hydrogenated to produce aviation gasoline.

Another catalytic process used in the manufacture of commercially pure iso-octane (100 octane number) is as follows: a charging stock rich in isobutene is selected and sent to the catalytic chamber maintained at a temperature of 260-325° F. under a pressure of 700 pounds. The product is distilled to segregate the iso-octylene fraction. The latter is converted to iso-octane by catalytic hydrogenation with a nickel catalyst at a temperature of 325° F. and a pressure of 75 pounds.

The demand for iso-butane, used in the alkylation process for aviation gasoline manufacture, has made it necessary to produce this hydrocarbon synthetically. Isomerization may be considered to be the alteration of molecular structive without changing the number of carbon and hydrogen atoms present. Butane, in the presence of an aluminum chloride catalyst, is changed into iso-butane with yields of 75 percent of the theoetical.

Dehydrogenation, or the removal of part of the hydrogen from other hydrocarbons, has several applications. Paraffin hydrocarbons may be reduced to unsaturates and then fed to polymerization units. For example, the C_2, C_3, and C_4, paraffins are converted to the corresponding olefins at a temperature of 930-1290° F. and in the presence of a chromium oxide catalyst on alumina. Another application is the dehydrogenation of heptane, or other straight-chain paraffins, to produce toluene, and other aromatics. For example, a low-octane number naphtha is passed over a granular catalyst at a temperature of 1000° F. in the presence of hydrogen gas. An 80 percent yield of 80 octane gasoline is produced, which is high in benzene and toluene content.

Catalysis has equally broad applications in the heavy chemicals industry. The contact process for sulfuric acid manufacture became a firmly established industrial process at the turn of the century. Until about 15 years ago, the catalytic material was mainly finely divided platinum on an asbestos carrier or on a calcined magnesium sulfate carrier. Iron oxide also has been used as a catalyst. In 1926, vanadium pentoxide was introduced as a contact material. This less expensive agent is not used as such, but is always supported by an inert carrier such as diatomaceous earth, which does not melt at the high temperatures employed (about 842° F.) The difficult step in the manufacture of sulfuric acid is the change of sulfuric dioxide to sulfur trioxide. If sulfur burned to form the trioxide, the problem would be an easy one; but it burns to the dioxide only:

$$S + O_2 = SO_2$$

In the contact process, when sulfur dioxide and oxygen are passed over a catalyst at the proper temperature, they unite to form the desired sulfur trioxide, which, with water, give sulfuric acid:

$$2\ SO_2 + O_2 = 2\ SO_3$$

The sulfur trioxide dissolves explosively in water, but in sulfuric acid of 98 percent strength, it dissolves smoothly, and this acid is the common absorbent. The pressure on the gases as they pass over the contact bed is essentially atmospheric. The life of the catalyst is considered to be about 10 years.

Until about 12 years ago, nitric acid was manufactured exclusively by the action of sulfuric acid on chile saltpeter.

$$2\ NaNO_3 + H_2\ SO_4 = 2HNO_3 + Na_2SO_4$$

Since then the manufacture of nitric acid by the catalytic oxidation of ammonia with atmospheric oxygen has become the standard process.

Ammonia gas and air (11 percent ammonia) is passed through a fine wire gauze of activated platinum raised to a glowing heat (1876° F.). The gauze is of the fineness of silk and a contact time of only 0.0014 seconds is required. The first reaction is to form nitric oxide:

$$4NH_3 + 5O_2 = 4NO + 6H_2O$$

The dioxide reacts with water to form nitric acid:

$$3NO_2 + H_2O = 2\ HNO_3 = NO$$

The acid from the absorption tower is 50 percent nitric acid. If a higher concentration of acid is desired, it is necessary to distill a mixture of 93 percent sulfuric acid and the 50 percent nitric acid. The nitric acid passes out while the water is retained in the sulfuric acid in the retort.

The Haber-Bosch process in 1934 was the most widely used and most successful type of plant for the synthetic production of ammonia. A mix-

(*Continued on page* 78)

Combination Plant Swells Flow Of Petroleum War Supplies

IN PLANNING the adaptation of the American refining industry to the provision of vastly increased quantities of aviation fuel and other specialized products required for the conduct of the war one of the important moves projected by the Petroleum Administration in consultation with refiners in different parts of the country was the utilization of the resources of some of the smaller refining plants for this purpose. To meet the conditions of refiners whose individual production of light elements was not sufficient to justify the construction of separate units for transforming these into final products the idea of combination plants was proposed.

These projects called for the building of plants at central points to handle light ends from a number of neighboring refiners and to convert these into aviation fuel or other desired products. The materials to feed the central plant are conveyed from the participating refineries, in most cases by fleets of trucks especialy equipped for this service. A number of such projects have been undertaken and their joint contribution to the flow of war materials is providing a noteworthy and steadily growing addition to the total supply.

An interesting example of this type of war plant is rapidly taking form in Southern Oklahoma where it is being equipped to produce all the components of 100 octane gasoline, blend them together and deliver finished motor fuel of the quality required by the nation's fighting planes. The plant is the first of its kind in Oklahoma to be built entirely for war production. It represents the joint determination of eight independent Oklahoma and Texas refiners to aid the war effort more effectively than they could do it by individual efforts.

These refiners are Anderson-Prichard Company, Bell Oil & Gas Company, Ben Franklin Refining Company, Cosco Oil Company, La Salle Petroleum Corporation, Panhandle Refining Company, Rock Island Refining Company, and W. T. Waggoner Estate.

They have organized a new company, Associated Refineries, Inc., to build and operate the war products refinery. M. Lloyd Freese of Bell Oil & Gas Company is president and general manager of Associated Refineries, Inc. L. B. Simmons, president of Rock Island Refining Company, is chairman of the board. The other directors are: B. I. Lubell, R. V. Anderson, J. S. Cosden, Jr., L. H. Prichard, R. C. Stanford, P. D. Williams, and H. B. Alspaugh.

The eight refiners are making certain necessary changes and revamping certain equipment in their individual plants in order to fulfill their parts in the contract to contribute needed raw materials to the Associated Refineries plant. They will continue operation of their refineries throughout the war, thus assuring that there will be no disturbance of crude connections or refinery operation in southern Oklahoma and north Texas.

The Associated refinery will cost about $10,000,000. The catalytic units for the production of aviation gasoline were designed by Universal Oil Products Company and will be operated under license from that company. The plant is being financed by Defense Plant Corporation through Associated Refineries, Inc. The contract for its construction has been let to the Frick-Reid Supply Corporation. One of the interesting features is a fluid bow catalytic cracking unit, similar to those installed in some thirty refineries recently completed or now in process of construction. Three of these units are in commercial operation producing high yields of aviation gasoline, and a number of others are under construction throughout the country. The Associated unit is about 200 feet high, equal to a 20-story office building. Other catalytic units are a H. F. Alkylation unit and an isomerization unit, both of Universal Oil Products design.

These catalytic units make possible the production of base stocks and alkylates and blending them to the desired specification for 100-octane aviation gasoline. The refinery possesses great flexibility which makes it possible to meet variation of specifications as required.

Despite the difficulties encountered, construction of the plant is proceeding rapidly. Buildings are fast taking shape—office buildings, laboratories, pump houses and other structures, along with the construction of the process units. Building operations were badly hampered at first by the poor condition of the roads, which has been partly remedied, and by a shortage of housing, which is still serious. It is expected however that 100 housing units will be built through the National Housing Administration to take care of additional workers who will be required.

The Associated plant will not at present make any raw materials for conversion into synthetic rubber, but will confine itself to the conversion of its raw materials. While the refinery is built to be used exclusively for the duration in the production of war material, it can easily be adapted to peacetime production because of its great flexibility. Its successful operation may very well mark a milestone in refinery development in the Southwest. In the meantime it is of vital import that many fighting and bombing planes will operate on the 100-octane gasoline produced by this combination plant.

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How about your crude?

If you are a refiner still making peacetime products the following statement is no news to you:

> Generally firm tone continuing in petroleum markets reflects the fact that *many refiners are in difficulties over the question of adequate crude supplies*

That is from Keith Fanshier's oil page in the Chicago Journal of Commerce, April 30, 1943

Further down in his column Mr Fanshier writes:

> No question about it; high octane aviation gasoline [100-octane] is needed in staggering quantities and ever greater ones

Refineries that can make 100-octane gasoline, any component of it or any other war product *must* have adequate crude supplies—and they do

It's wise and patriotic for every refiner to get into war production

Helping to convert refineries to war production is our job

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THE REFINERS INSTITUTE OF PETROLEUM TECHNOLOGY

CATALYSTS' IMPORTANT ROLE IN WAR INDUSTRY

(*Continued from page* 75)

ture of hydrogen and nitrogen gas is passed over an iron oxide catalyst at a temperature of 1022° F. and a pressure of 3000 pounds. The American Sytem developed by the Fixed Nitrogen Research Laboratory uses a temperature of 887° F., an iron oxide catalyst and 4500 pounds pressure. The basic reaction is

$$N_2 + 3H_3 = 2\ NH_3$$

The catalyst used in the American system consists of iron oxide granules containing "promoters" of potassium and aluminum oxides. The life of the catalyst is about 100 days. The use of a temperature much higher than 900° F. greatly shortens the life of the mass.

Acetylene, generated in the conventional manner from calcium carbide and water, is the starting chemical for the manufacture of synthetic acetic acid. Mercurous sulfate is the catalyst which causes the acetylene to react with water at 154° F. temperature to form acetaldehyde:

$$C_2\ H_2 + H_2O = 2\ CH_3\ CHO$$

From acetaldehyde, several chemicals are formed by catalytic reactions. Acetic acid is formed when air is bubbled into a mixture of acetaldehyde and 0.5 percent by weight of manganese sulfate at a temperature of 149° F. and a pressure of 50 pounds:

$$2CH_3CHO + O_2 - 2\ CH_3\ COOH$$

The acid is redistilled to make glacial, 99 percent acetic acid. The function of the manganese catalyst is not to catalyze the oxidation of the aldehyde, but rather to decompose an intermediate product, per-acetic acid, which is explosive; as it decomposes, the desired acetic acid forms. The production of synthetic acetic acid in 1940 was 186,000,000 pounds.

A host of organic chemicals is manufactured today by catalytic methods. To indicate the range mention may be made of the production of methanol (wood alcohol) by this method of the conversion of starch to glucose, the hydrogenation of vegetable oils, the vulcanization of rubber, the manufacture of formaldehyde, ethylene glycol (anti-freeze) and of resin plastics. In fact the many uses to which catalysis is being and can be applied entitle it to be regarded as a veritable cornerstone of modern chemical progress.

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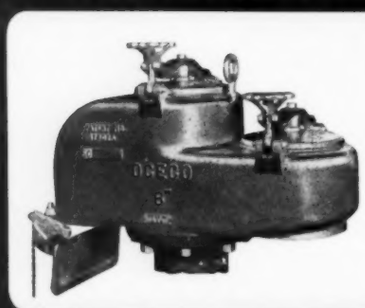

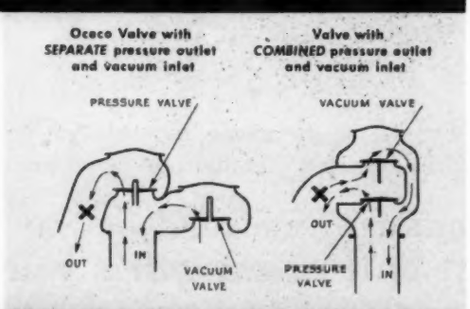

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As shown by the diagram above, a flash of vapors leaving the tank at point marked X in Oceco's separate outlet valve, tends to close the pressure valve without opening the vacuum valve. In the combined outlet valve design, the flash has maximum opportunity to open the vacuum valve and find easy entrance into the tank.

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East Coast Toluene Plant

An important addition to the toluene resources of the country was marked by the opening of a large unit in the Philadelphia area early in July. This plant built by Gulf Oil Corporation entirely from its own funds but constructed at the request of Army Ordnance was the second of its kind on the Atlantic Coast. Most other toluene plants are located in the South and West.

The charge used in the plant is straight run gasoline from which toluene is extracted in a series of fractionating columns. The product goes entirely to the government for war use and the capacity is a military secret. The plant was built under high priority ratings by Foster Wheeler Corporation.

Pipe Line Contract Awarded

Bechtel-Dempsey-Price has been awarded the construction contract by Panhandle Eastern Pipe Line Company covering the building of approximately 120 miles of 26-in. loops and taking up and relaying 35 miles of 22-in. line. These sections parallel the Panhandle main line from Moore County, Texas, to Kansas City. Work started on the project last week and it is anticipated that it will be completed this fall. The building of these loops will increase the Panhandle daily gas flow approximately ninety million cubic feet, which will be utilized in most part by war plants. The three contractors who have pooled their resources under the name of Bechtel-Dempsey-Price are: The Bechtel Company, San Francisco, California; O. E. Dempsey Construction Company, Tulsa, Okla.; H. C. Price Co., Bartlesville, Okla.

Record Tank Car Movement

In the week ended July 10 tank car loadings of oil broke all previous records with a total of 1,017,219 barrels. This is the first time the million barrel mark has been exceeded and is far in excess of the highest estimates made by transportation officials at the time when the expansion of the railway movement of oil was undertaken.

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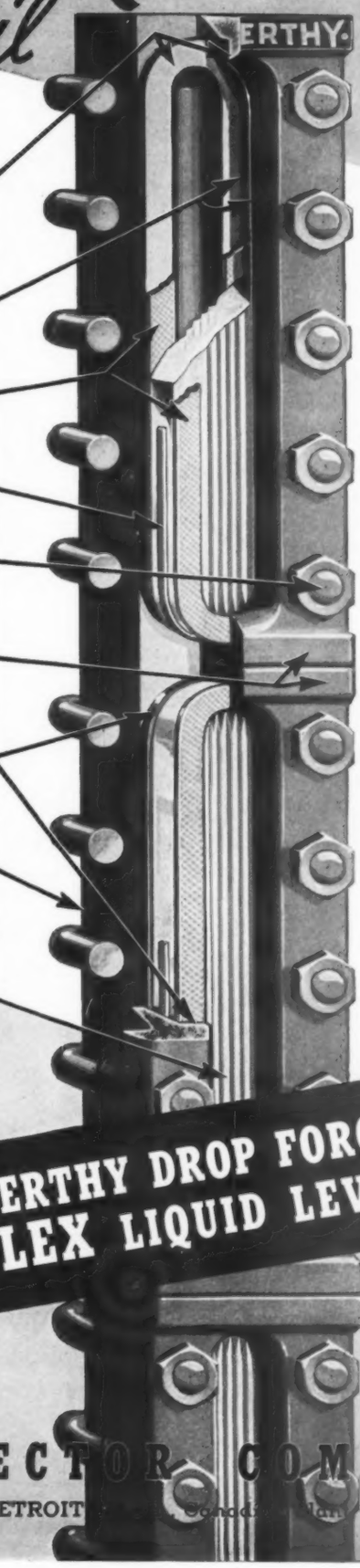

1 **GLASS AFFORDED EVERY PROTECTION.** Frame completely contains the glass so that no part is exposed. Weight of frame entirely supported by liquid chamber gland . . . not by glass.

2 **UNIFORM GASKET PRESSURE ASSURED** by accurate finishing of the retaining surfaces to very close tolerances.

3 **EQUAL RESILIENCE ON BOTH SIDES OF GLASS** due to interchangeable gaskets which also eliminate possibility of improper reassembly in field.

4 Spacing band centers glass and prevents contact with metal.

5 **PERFECT GASKET JOINTS WITH MINIMUM BOLT TENSION** because misalignment of parts is impossible, which also eliminates frequent cause of glass breakage.

6 **DISTORTION PREVENTED** by reinforcing beam and scientific distribution of metal in frame. (Distortion causes excessive strains in glass and results in breakage.)

7 **GASKET BLOW-OUTS PREVENTED** by full metal backing of entire surface and periphery of both gaskets.

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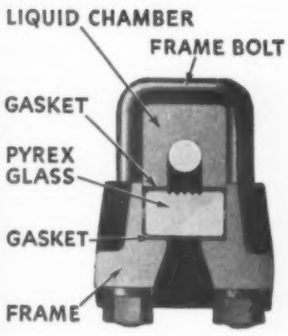
9 **PYREX GLASS** is used exclusively because of its greater strength and resistance to thermal shock and erosion. Exhaustive comparative tests have proven conclusively that Pyrex glass is the highest grade obtainable for the service.



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Ickes Pays Tribute to Oil Industry

IN a brief volume entitled "Fighting Oil" Petroleum Administrator Ickes has set down for the benefit of the public the important facts about the part played by oil in the world conflict now raging, tells how difficult problems have been met and solved through government-industry cooperation and describes the organization and operation of the Office of Petroleum Administration. Mr. Ickes obviously is proud of the effective team work between his organization and the members of the oil industry. In the pages of his latest volume he repeatedly gives high credit to the oil men of the country for their all-out support of national needs and for the industrial miracles they have accomplished in meeting extraordinary demands.

Thus, one chapter of his book opens with the following sentence: "If I were asked to name the most important intangible contribution to the success of our wartime petroleum problem I would unhesitatingly point to the cooperation that has existed between the government and the oil industry from the outset."

In an effort to convey some understanding of the tremendous proportions of the task shouldered by the American oil industry Mr. Ickes says:

"We may be sure that without oil this war would not have been fought on its present grand scale. . . . If therefore oil has set the pace for the war oil must see it through and the side that can throw the most oil into the fray over the longest sustained period of time will win.

"'Since the Nazis and the Japanazis started on the rampage, the world of science and invention has accomplished what normally it would have taken 50 years to do. This is especially true of the American petroleum industry. Since they found themselves face to face with the job of furnishing power to the biggest part of a world under arms, American oil men have been moving in the stratospheric reaches. . . . With the biggest o der of its life to fill, they went to work with grim determination and became, as much as any other single factor, responsible for the means by which the war is being fought, and by which it will be won eventually by the United Nations.

"There is no denying that there have been blue Mondays when I have wondered if our production and transportation of petroleum could possibly keep pace with the growing military and essential civilian needs. If it does, let me say right here, without fear of successful contradiction, that we will have been a witness to a miracle worthy of the saints of old.

"It will, in other words, be little short of a metaphysical achievement to fuel the 185,000 American bombers and fighting planes that we expect to have in the air before 'finis' is written to the war; the 18 million tons of merchant ships that we have been promising ourselves; the 120,000 tanks that will one day soon be blazing away at the enemy; not to mention the hundreds of thousands of trucks and other vehicles that carry supplies to the front. Without oil, every piece would be just so much scrap metal—and no more. Having fueled and lubricated these gasoline and oil eaters of land and air, we will have only started the job. We will still have our Navy to supply; we will still have to keep our allies stocked so that their bombers and tanks and mobile artillery may be kept moving; we will still have to feed the automobile tanks of our defense workers and, within reason, meet the essential needs of our civilian populations; and we will still have to pour oil into the thousands of war industries working three shifts a day, and into the many millions of homes and buildings that have no substitute for oil heat.

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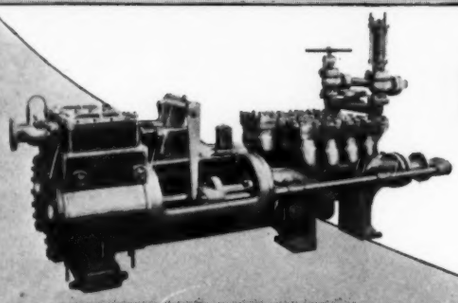

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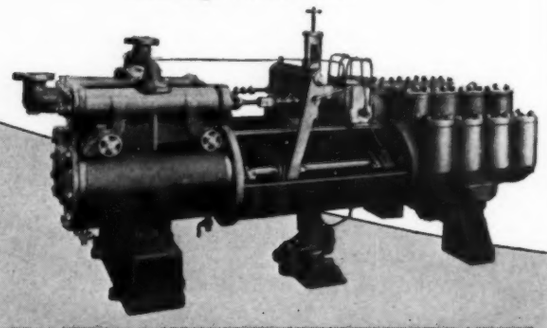

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"Every one of the thousands of bombers that are taking off daily for a go at the enemy must carry enough gasoline for the trip home, so that when we speak of a flying radius of 1,000 miles we are speaking in terms of a gasoline volume never before thought possible of achievement. We are going to see bigger and ever-bigger air fleets, made up of ever-larger planes, capable of negotiating longer and ever-lengthening distances, and for these myriad giants of the air we must brew a particular type of gasoline which, until a few years ago, had been only a laboratory curiosity. In addition to this specialized gasoline for the fliers, plus unlimited quantities of high-quality gasoline for our tanks and trucks, and fuel for the Navy, together with high-grade lubricants for virtually every use abroad and at home, we must produce prodigious amounts of toluene for quantity production of explosives, and butadiene for the manufacture of synthetic rubber.

"It has been reliably estimated that about 60 percent, or nearly two out of every three tons of the supplies sent overseas to our expeditionary forces are oil.

"Under-Secretary of War Robert P. Patterson has made the startling statement that the gasoline supply for the military services in North Africa is 'on the basis of a planned requirement of 10 gallons per day per vehicle. . . .' Now there are literally hundreds of thousands of supply trucks and armored vehicles belonging to the Allied nations that are drawing on the United States for the major portion of their fuel supply. Multiply the number by ten and you may get a faint notion of the petroleum that is needed every day to keep our army rolling.

"We have the word of British officials that a battleship, on a short cruise, will consume in the neighborhood of a million gallons of oil, and that the consumption by the British Navy is measured by tens of millions of gallons a week. What is true of England's Navy is equally true of our own.

"Does anyone know of a word, or a combination of words, that adequately describes the size of the job and the responsibility that faces petroleum in this fight? If he does, I would like to have it to add to my vocabulary because I, for one, am hopelessly lost for language to express them.

"But for all its enormity the job is going to be done simply because it has to be done—and a better reason than that I wouldn't be able to give."

FIGHTING OIL: By Harold L. Ickes, 174 pages Published by Alfred A. Knopf, New York, 1943. Price $1.75.

New Bead Catalyst

(*Continued from page* 60)

To its originators, however, the great advantage of the bead catalyst is its high activity and the increased yields of aviation gasoline base stock obtained by its use. Coupled with this is the increased power output of the gasoline made with it which will add to the fighting ability of the nation's aircraft during the war and impart increased usefulness to engine performance in time of peace.

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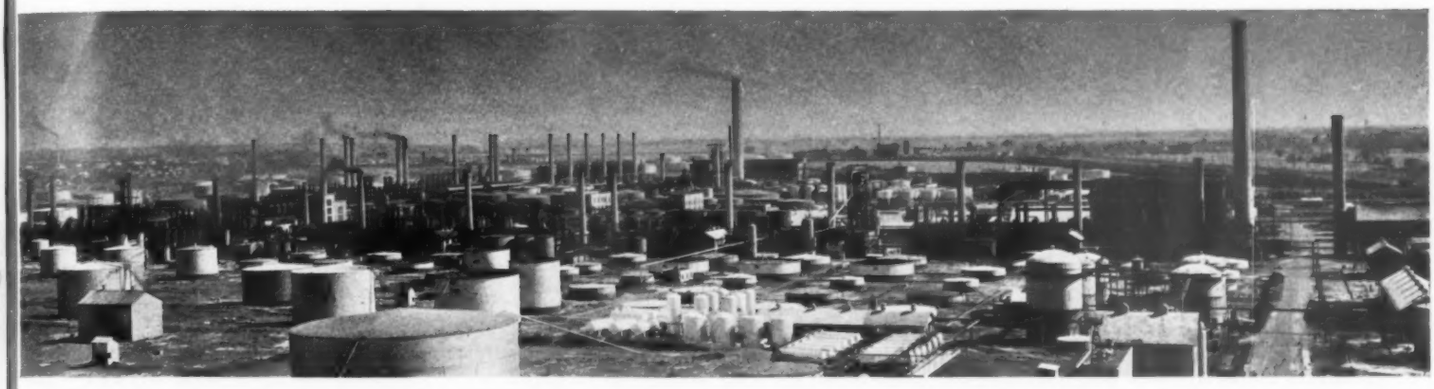

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DESALTING DEHYDRATING

ISOMERIZING, A NEW TOOL FOR MAKING AVIATION GASOLINE

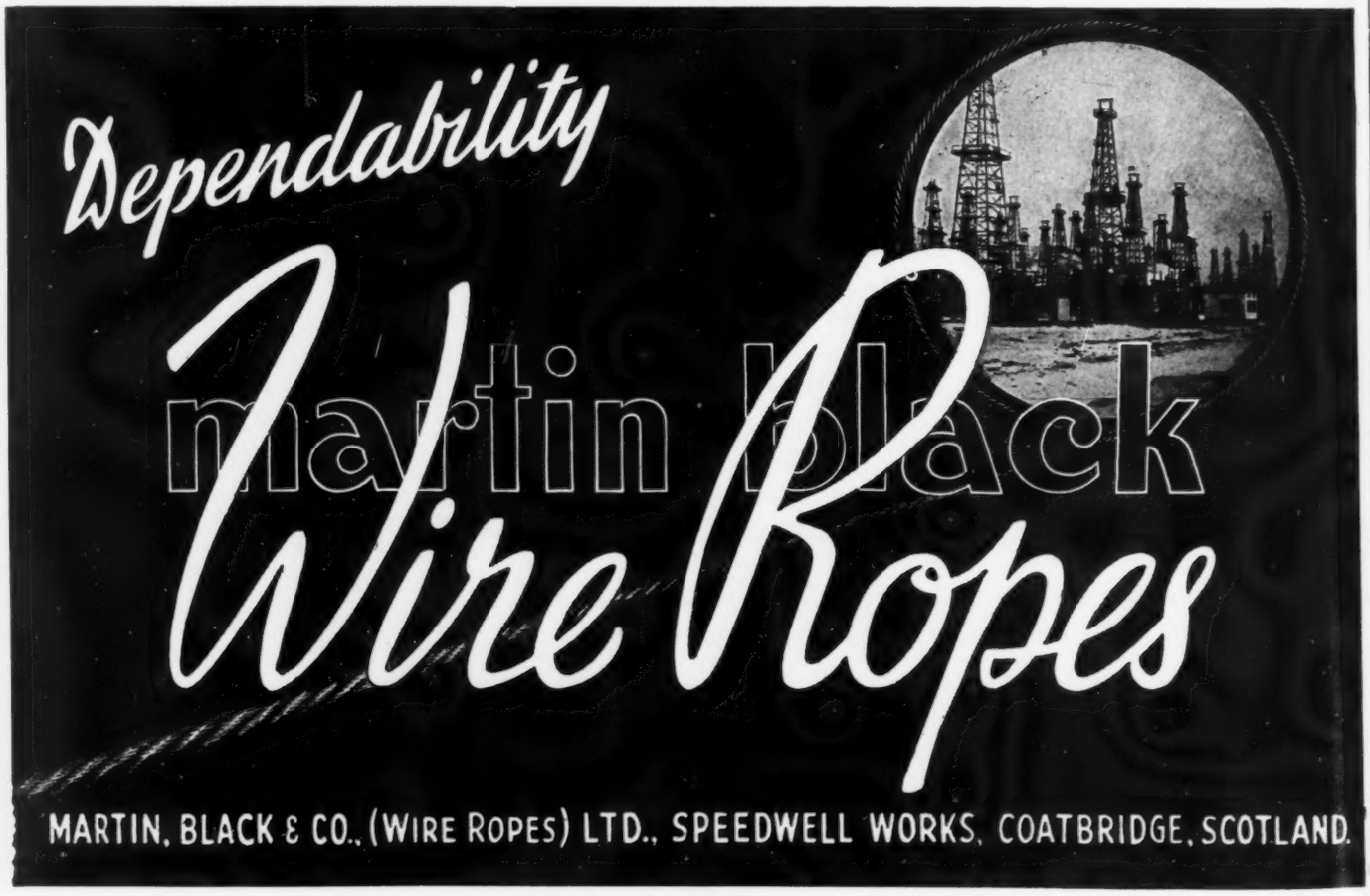
(*Continued from page* 66)

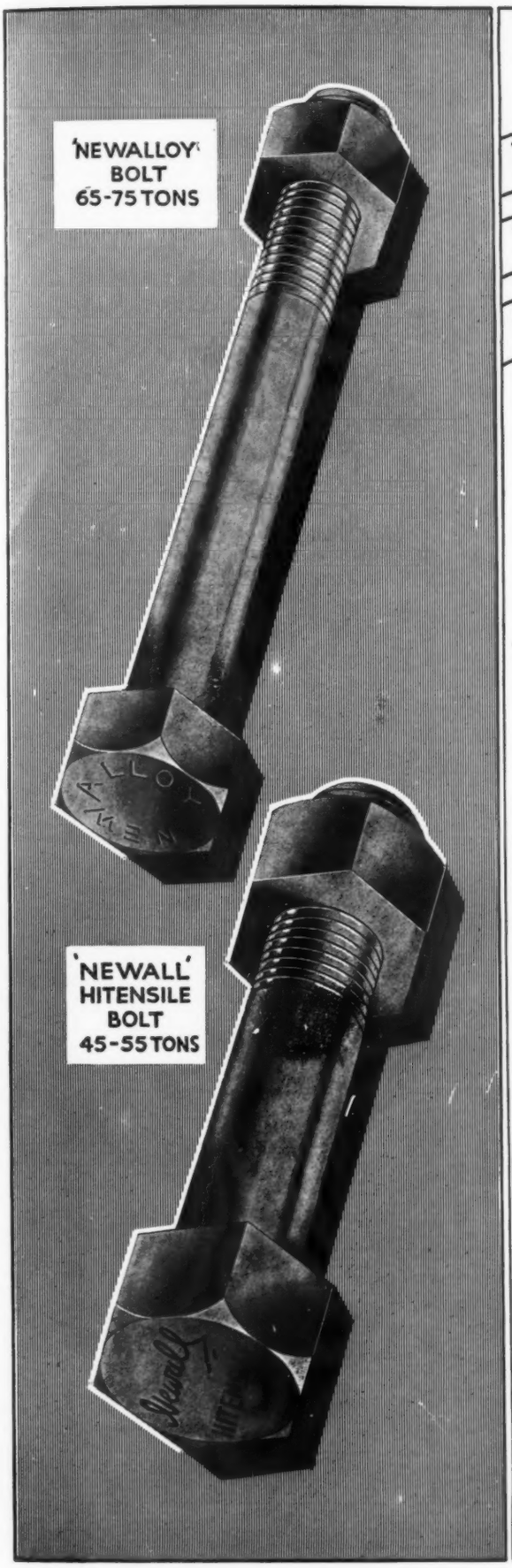
hardly possible to limit the reaction merely to isomerization. Some cracking of the butanes is likely to occur, resulting in the formation of olefins, which to some extent may polymerize; this is especially the case if the feed is not quite pure but contains some C_5 or higher hydrocarbons. The olefinic cracked products are quite reactive and may combine with the aluminum chloride catalyst to form organic complexes, reducing its efficiency and shortening its life. One complaint about the vapor phase process is that the rate of corrosion of the equipment is fairly high.

Recent attempts to avoid the inconveniences of vapor phase isomerization have met with distinct success through the development of liquid phase processes. One such process is said to have been brought to commercial perfection by The Texas Development Company; the Standard Oil Company of Indiana is also said to have developed a liquid phase isomerization process of its own, but no details of these processes are as yet available. Another liquid phase process has been carried through to commercial operation by the Shell Development Company. A plant functioning by this process has been working since February, 1943, at Shell Oil Company's Houston refinery and there is another similar Shell plant in Canada. The process has been thrown open to general licensing.

No details or flow of sheets of the Shell liquid phase isomerization process will be available for publication until after the war. It has been given out, however, that the process has been made possible by the use of a non-aqueous solvent for aluminum chloride. This solution is pumpable, so that the catalyst can be brought into the reactor as a flowing liquid rather than as a fixed bed of solid. The same solvent will absorb the charge of normal butane and hydrochloric acid promoter so that an entirely homogenous liquid phase is substituted for the heterogenous vapor-solid phase system. This system has several advantages. In the first place, the operation becomes continuous instead of intermittent, and there is consequently no need for a multiplicity of reactors. The catalyst is kept up to full efficiency by continuous injection of fresh catalyst solution at the front end of the system; at the rear end a certain proportion of the catalyst solution is removed from the system and the aluminum chloride contained in it is rejuvenated in auxiliary equipment. Another distinction of this process is that the annoying corrosion that is noted in the vapor phase processes is greatly reduced. The percent of conversion is considerably better than in the vapor phase processes—50 percent (design contract) instead of around 40 or perhaps 45 percent. In actual practice the efficiency of conversion is said to have reached over 55 percent. This larger efficiency is in part ascribed to operating conditions which preclude the occurrence of cracking and the consequent absence of olefins that form organic complexes with aluminum chloride. This also appears to be a factor in helping to keep down corrosion of the equipment. The working life of the catalyst in the liquid phase process is said to be one and one-half times as long as in the vapor phase processes. The good working of the Shell liquid process requires careful supervision of the feed which should be as free as possible from olefins with minimum amounts of water and sulphur; for the stated reasons the amount of C_5 or higher hydrocarbons should be small.

It is said that the installation costs and strategic materials requirement are about the same for either the vapor phase or the liquid phase isomerization process—$300-$400 per barrel of rated daily capacity. The actual figure depends of course on the capacity of the plant the location, labor rates, etc. If the plant is built directly in connection with an alkylation plant the investment cost will naturally be reduced. The cost of producing isobutane by the Shell liquid phase process; including royalty, is less than 1 cent a gallon. Isopentane can also be produced by this process from pentane.





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WAR TIME EVOLUTION BRINGS MANY CHANGES IN OIL REFINING

(*Continued from page* 49)

diene was effected somewhat late. It is now impossible to scrap any of the more complex methods because the change-over would postpone the day when new supplies of tires can be made generally available for civilian use. But in the post-war period the direct conversion of butane into butadiene will most likely be the base for a surviving synthetic rubber industry.

The war has largely revolutionized one minor branch of the petroleum industry—the practical art of obtaining carbon black by the incomplete combustion of natural gas. Immense quantities of carbon black were used in the fabrication of automobile tires made of natural rubber. At that time the channel process was used for obtaining the hard grade of carbon black that was most suitable for the purpose. With the enforced shift from natural to synthetic rubber there had to be a shift from the hard to the soft blacks that were more in harmony with the properties of the synthetic product. Out of this necessity the channel process has evolved into two new processes, the furnace and the thermatomic processes. Besides attaining the desired quality the new processes give much larger yields; also, the new processes permit the manufacture of carbon black from liquid petroleum as well as from gaseous feed stock, and further have the advantage of better controllability.

A technological revolution less spectacular than that which has culminated in the new aviation gasoline industry, but one which is of only slightly less importance, has brought significant changes in the fabrication of lubricating oils. It is unnecessary to remark that airplanes require fuels of the very highest quality, and the same may just as truly be said of their requirement of lubrication. Engine trouble on a bombing or starfing flight is a serious matter, and inadequate lubrication may be a fruitful source of engine trouble. Airplanes operate under extremes of temperature and their lubricants must lubricate efficiently under all conditions. Military vehicles that operate on the ground also make unprecedented demands on the art of lubrication. The demand for heavy-duty lubricants has been especially insistent.

To meet this demand the lubricant compounders have had first of all to search out the crude oils that are richest in the necessary components, and since no natural petroleum fractions or mixtures thereof have all the required qualities it was necessary to develop additives that would make up for the deficiencies of the natural products. One way was to manufacture synthetic lubricants by polymerizing certain olefinic fractions; another was to call on other divisions of chemical industry for certain substances that have the property of flattening viscosity-temperature curves and keep pistons, cylinders and bearings free from carbon, gum and "varnish." The importance of these additives will be appreciated when it is understood that their scarcity, rather than the scarcity of mineral oil bases, has been responsible for bottleneck conditions in the production of military lubricants.

It is natural to raise the question as to how much of this war-born revolution in the oil refining industry will survive into the post-war period. It may be taken for granted that the production of super-100-octane number gasoline will be continued, and that the availability of these super-fuels will spur the automotive engine builders to utilize the full potentialities of these fuels. It may also be taken for granted that the refining methods for producing these fuels will be mostly one-stage or at least automatic and continuous processes. Alkylation methods will probably wane in favor of perfected isomerization and cycloversion processes. Cycloversion and catalytic treating will have additional reason for survival in that they are a source of nearly unlimited supplies of aromatics for the production of plastics, dyes, medicines and countless other chemical materials. Whether the United States will keep all or most of its new synthetic rubber industry will depend on politico-economic considerations of foreign trade policy, and there is the further question of whether the petroleum industry or the grain farmers will be allowed to furnish the raw material for the retained domestic industry.

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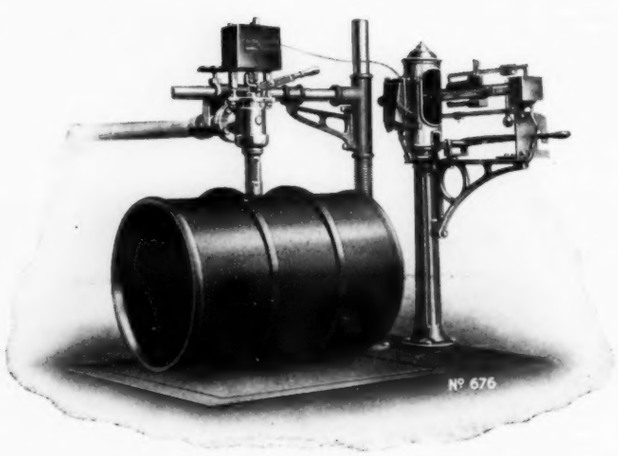

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